

USE OF CALCIUM CHLORIDE ACCELERATED HIGH EARLY STRENGTH CONCRETE FOR SLAB REPAIR AND REPLACEMENT

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A rapid strength developing, full depth patching system, utilizing type III Portland Cement concrete and using calcium chloride as an accelerator is described. Compressive strengths of 3000 psi are achieved in approximately four hours. The temperature of the concrete at the time of placement is $90^{\circ}\text{F} \pm 5^{\circ}\text{F}$. Procedures used to achieve these temperatures are described. Moisture barrier and insulation boards are used to enhance rapid strength development. An explanation of the kinetics of calcium chloride accelerated concrete hydration is presented. Various methods of re-establishing load transfer and cost comparisons between them are discussed.

Region 10 (Nassau and Suffolk Counties) has been plagued in recent years with rigid pavement buckling failures, usually occurring at transverse joints. Until five years ago the policy was to excavate the shattered portland cement concrete and replace it with asphalt concrete. This was expeditious but not without serious fault.

The fault was that the pavement slabs no longer functioned integrally as a unit. In hot weather with the joint openings filled with incompressibles, the pavement slabs would expand longitudinally, go into compression and crush into the asphalt repair. (The modulus of elasticity of asphalt concrete is as high as 1,300,000 psi in January but as low as 130,000 psi in July [1, 2]).

In cold weather the pavement system would not contract as an integral unit; instead, each slab would contract onto itself. This would leave the slabs in approximately the same position they occupied in the peak of the hot weather but with wider joint openings.

With each passing winter, more incompressibles would infiltrate into the joint openings. With each passing summer, the pavement system would expand and crush further into the asphalt repair; eventually creating a convex hump and shearing the longitudinal joint ties connecting contiguous lane panels (Figures 1 thru 6).

The situation described would lead to transverse joint faulting, longitudinal joint faulting, and loss of load transfer at both the

transverse and longitudinal joints (Figure 7, 8). There had to be a better way.

The better way was the design and implementation of a full depth pavement repair system utilizing a rapid strength developing portland cement concrete capable of achieving a compressive strength of 3000 psi in approximately four hours.

Material and Method--The Work Up

Region 10's main artery into and out of New York City is the Long Island Expressway (I-495). Its rush hour traffic densities preclude taking a lane out of service between the hours of 6:00-9:30 a.m. and 3:30-7:00 p.m. The material and method was controlled by this criterion.

Literature Search

The first undertaking was an intensive literature search. It yielded eight sources of useful information.

1. Mr. Jens Simonsen, Physical Research Engineer, Michigan Dept. of State Highways and Transportation, Lansing, Michigan.
2. Mr. Ken McGhee, Senior Research Scientist, Virginia Highway and Transportation Council, Charlottesville, Virginia.
3. The Nebraska Dept. of Roads, Lincoln, Nebraska.
4. Transportation Research Board, National Academy of Sciences, Washington, D.C.
5. The Portland Cement Association, Skokie, Ill.
6. The American Society of Civil Engineers, New York, N.Y.
7. The American Concrete Institute, Detroit, Michigan.
8. Federal Highway Administration (Implementation and Demonstration Projects Divisions), Washington D.C.

Based on information obtained from these sources and with the help and resources of the Albany Materials Bureau, the following design criteria was established.

Concrete Design Criteria

1. The cement would be Type III Portland Cement.
2. The cement weight per cubic yard would be 826 pounds.
3. The temperature of the concrete at the time of discharge would be 90°F, ± 5°F.
4. After the concrete had taken initial set (thirty to forty minutes) the repair would be covered with a four mil polyethylene sheet and insulation boards, (thermal insulation value R-12).
5. The air entraining agent would be vinsol resin.
6. The accelerating admixture would be calcium chloride dihydrate ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$). It would be incorporated at a rate of 2% of the cement weight (later increased to 2.67%). It would be incorporated in solution form. The solution would contain 29% ± 1% calcium chloride (anhydrous).
7. Concrete placement operations would be permitted only when air temperature (shade) was within the range of 55° to 95°F; and only when the minimum temperatures for the forty-eight hours immediately after placement would not be lower than 40°F, based on National Weather Service forecasts.
8. The water-cement ratio would be .39. This would include stone and sand moisture as well as the water used in the calcium chloride solution.
9. Welded wire fabric meeting the requirements of ASTM, A 185, would be placed in all repairs at a depth of 3 inches below the repair surface.
10. The method of concrete placement would be by concrete mobile. (At a later date drum mixers with specific modifications were permitted. This method is presently under evaluation.)
11. Concrete cylinders cast for the purpose of compression testing would be cured autogenously i.e., completely insulated and enclosed in sealed polyethylene bags.
12. A Schmidt rebound hammer would be used in the field, to ascertain the approximate compressive strength of the concrete.
13. When the concrete had achieved a compressive strength of 2000 psi, the insulation boards and the polyethylene sheet would be removed; and the surface of the concrete would be coated with white pigmented curing compound at a rate of one gallon per 150 sq. ft.

Discussion of The Design Criteria

The design criteria described represents a rapid heat liberating system. This is due to the nature of the constituent parts and proportions. This and the fact that the insulation boards lock in the liberated heat of hydration, creates an autogenous accelerated curing system, enhancing the rapid development of strength.

Type III Portland Cement

Type III Portland Cement has a specific surface of approximately 5000 cm^2/g . (Blaine). This is almost 1.5 times greater than that of Type I or Type II Portland Cement. The high specific surface provides more sites of attack by water and as such it increases the rate of hydration and heat liberation. Also Type III Portland Cement has the highest percentage of tricalcium silicate of any of

the Portland Cements. Its tricalcium silicate content is 60%; whereas, Type I and Type II contain 50% and 40% respectively. This is very important, in that the tricalcium silicate [$3\text{CaO} \cdot \text{SiO}_2$ or C_3S] has a much higher heat of hydration than does the dicalcium silicate [$2\text{CaO} \cdot \text{SiO}_2$ or C_2S] and it is the constituent most active in the early stages of hydration (C_3S is inactive for approximately the first 48 hours).

Discharge temperature of the Concrete

An old axiom of reaction kinetics states "Reaction rates increase by a factor of two for every 20°F rise in temperature." Figure 9 illustrates this rather dramatically, as does the data presented below. Working with the same batch but with different discharge temperatures, the compressive strength of the concrete yielded as follows:

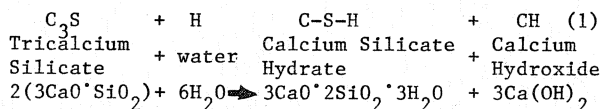
DISCHARGE TEMP.	TIME	COMPRESSIVE STRENGTH
80°F	3 hrs.	1326 psi
90°F	3 hrs.	2122 psi

To insure that the concrete discharge temperature is maintained at 90°F ± 5°F, the mix water is heated to such temperatures necessary to accomplish this. Field experience has demonstrated that the temperature difference between the aggregate-cement temperature and the desired discharge temperature, multiplied by a factor of 3.5; and that product, added to the initial aggregate-cement temperature, would yield the water temperature necessary to achieve the design concrete discharge temperature. If any adjustments are necessary, they are relayed back to the contractor.

We have successfully executed systems with the mix water heated to temperatures as high as 180°F. Upon incorporation with the system the resultant temperature change is virtually instantaneous. When using drum mixers it is recommended that the system be dry mixed twenty revolutions before adding water. With concrete mobiles there are no special procedures necessary.

The Accelerating Admixture-Calcium Chloride

The Chemistry-Background. The major reaction products of hydrated tricalcium silicate (C_3S) are calcium silicate hydrate, ($3\text{CaO} \cdot 2\text{SiO}_2 \cdot 3\text{H}_2\text{O}$) or abbreviation C-S-H and calcium hydroxide, $\text{Ca}(\text{OH})_2$ or abbreviation CH. The C-S-H is largely a microcrystalline, amorphous gel of enormous surface area (500 m^2/g) and occupies about 70% (volume) of the hydrated material. The calcium hydroxide is crystalline and occupies about 20% (volume) of the hydrated material. They are formed as follows;



The calcium silicate hydrate provides the cohesive matrix responsible for strength development, and as such is the reaction product most responsible for the engineering properties of Portland Cement.

The Chemistry-Kinetics. The first step in the hydrolysis of C_3S appears to be one mole of H_2O for one mole of CaO , a very rapid reaction. Hydrolysis proceeds by an attack of water on the surface of the cement grains, causing the reactive components to pass into the ionic state. Ca^{++} and OH^- ions rapidly approach levels of high concentration. A solution close to saturation with respect to calcium hydroxide is quickly formed. Ca^{++} and OH^- ions are now leached from C_3S into a solution of increasing chemical potential. This makes their continued release more difficult. As a result the reaction rate slows down and the system enters the "dormancy period" (Figure 10 and 11).

While in the dormancy period the ion concentration slowly approaches and passes into supersaturation. In approximately 2-1/2 hours, a level of supersaturation 1.5 to 2.0 times the saturation level is achieved, enabling stable calcium hydroxide crystals to nucleate, take form, and commence to precipitate out of solution at a very rapid rate (Figure 11) [3].

The precipitating $Ca(OH)_2$ crystals act as a sink for Ca^{++} and OH^- ions in solution; and as such causes them to flow rapidly to, and become incorporated into the newly formed crystal. The solution's ionic concentration level drops. This in turn, enhances the further dissolution and reaction of C_3S .

This new rate of reaction and Ca^{++} , OH^- ion release, is controlled by the rate at which stable calcium hydroxide crystals nucleate, take form, and precipitate; which is very rapid. The system exits dormancy and enters the "acceleration period" (Figure 10). A concomitant rigidity begins taking place within the system as stable reaction products take form as calcium silicate hydrate and calcium hydroxide. This rigidity is "initial set."

Discussion. One would expect that once the Ca^{++} , OH^- ionic concentration levels had surpassed saturation, that equilibrium would be re-established by crystallization. But, such is not the case for at least two hours. Why?

According to Nate Greening [4] and reported by Francis Young [5], free silicate ions, present in small but not insignificant quantity, adsorb onto the nuclei of newly formed calcium hydroxide crystals, thereby poisoning their growth. And until the level of supersaturation (with regard to Ca^{++} , OH^- ion concentration) is sufficiently large enough to overwhelm and overcome that poisoning effect, the system will remain in the dormancy period and no rapid reaction rates will take place.

Calcium Chloride. "Any compound that hastens the nucleation and growth of $Ca(OH)_2$ will act as an accelerator. Calcium chloride is the most effective accelerator because it supplies more calcium ion for a unit weight. At equal molarities, different calcium salts have similar accelerating powers [5]."

The time required for the system to achieve an ion concentration level of sufficient magnitude to overwhelm and overcome the poisoning effects described is approximately 2-1/2 hours.

However, through the addition of calcium chloride, the system is literally swamped with calcium ions. This almost immediately brings about the equivalent supersaturation level necessary to overwhelm and overcome the poisoning effects described; thereby enabling the system to exit dormancy and enter the acceleration period in

approximately thirty minutes (Figure 12).

The dormancy period has been virtually eliminated.

Autogenous Curing of Test Cylinders

It is important to keep in mind that because of the insulation boards, we are in effect curing the system autogenously. It was Ken McGhee of Virginia TRC, who apprised us of the need for autogenous curing of compression break cylinders.

It is recommended that the curing box conform to the criteria put forth in ASTM standard C 684, (1982-Part 14): Appendix X 1.2 and Figure X 1.2.

It may be of interest to note that the temperature of the concrete may reach as high as 180°F in four hours, (Figure 13) at which time it begins to descend. It is this high temperature and its containment that allow for rapid strength development in so short a time interval.

Field Problems and The Solutions Thereto

$CaCl_2$ Reaction With The Air Entraining Agent

When using a concrete mobile, it was found that if the calcium chloride solution and the air entraining agent entered the mixing auger at the same location, they would interact antagonistically. The result was no rapid strength. By separating the entry point of the two admixtures the problem was solved. The specification was changed to read; "The system (Concrete Mobile) shall introduce the calcium chloride and the air entraining agent at two separate points in the mixing auger. The calcium chloride shall be introduced at the same point as the mixing water. The air entraining agent shall be separated from this point by a distance of one foot. This separation shall be accomplished by the extension of a tube carrying the air entraining agent in a manner satisfactory to the Regional Materials Engineer [6]."

Alkali Reaction With $CaCl_2 \cdot 2H_2O$

Not all Type III cements gave the same results with regards to rapid strength development. Some were decidedly better than others. It was found that high alkali cements performed poorly in this regard, when compared to low alkali cements. Nate Greening informed us that the water soluble alkalies were reacting with the $CaCl_2$ and taking calcium ions out of solution; the effect of which was the lengthening of the dormancy period. To overcome that effect, we increased the amount of $CaCl_2 \cdot 2H_2O$ to 2.67%.

Analysis. What follows is an analysis of the reaction that takes place between $CaCl_2 \cdot 2H_2O$ and the alkali K_2SO_4 .

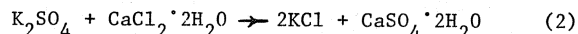
A chemical analysis of a high alkali Type III cement clinker (with regard to alkali and sulfate content) is as follows:

$$K_2O = 1.08\%$$

$$SO_3 = 1.40\%$$

The SO_3 will combine with most of the K_2O to form K_2SO_4 in a quantity equal to 2% of the Type III clinker by weight.

The K_2SO_4 is water soluble and as such will enter into reaction with $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ as follows:



The gram molecular weight of K_2SO_4 is 174.

The gram molecular weight of $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ is 147.

$$\frac{2\%}{174} = \frac{x\%}{147}; 174x = 294; x = 1.689 = 1.7\% \quad (3)$$

Two percent K_2SO_4 can take as much as 1.7% of $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ out of solution.

This leaves the system with 0.3% $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, and as such, not enough compound to supply the required number of calcium ions needed to allow the system to exit dormancy.

By increasing the amount of calcium chloride dihydrate to 2.67% the following is achieved.

$$0.30\% + .67\% = .97\% \quad (4)$$

The system now has approximately 1.0% $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ and as such will supply the required number of calcium ions needed to take the system out of the dormancy period in the time interval required.

High Water Cement Ratio

Contractors love high water cement ratios. We had some very serious problems in this regard. To demonstrate the efficacy of the design .39 water cement ratio, we ran a test using different slumps with the same batch of concrete (using a concrete mobile). It yielded as follows:

SLUMP	TIME IN HOURS	COMPRESSIVE STRENGTH
2-3/4"	3	2122 psi
4"	3	937 psi
5-1/2"	3	725 psi

In the case of the 4" and 5 1/2" slumps, the data indicates the time interval of the dormancy period to have been appreciably extended.

By increasing the water volume, the quantity demand for calcium ions is increased, and as such more time is required for the system to achieve the necessary supersaturation level. Hence, a longer dormancy period.

Variables

Prudence requires that tests be run on all cements, aggregates and admixtures, before permitting their incorporation into contract work. All Type III cements are not exactly the same. Some are uniquely different. To insure a uniform quality product, we require that; "The Contractor shall supply the Regional Materials Engineer with three bags of cement, 500 lbs. of each fine and coarse aggregate, 1 quart of each admixture, and 10 lbs. of calcium chloride flake or two gallons of calcium chloride liquid for laboratory trial batches [6]."

Discussion

By paying close attention to the details outlined and described above, compressive strengths of 2000 psi in less than 3.5 hours and 3000 psi in less than 4.5 hours are consistently achieved.

Alternate Methods of Re-establishing Load Transfer

Method #1-- Inverted T Sleeper Slab Method (Figure 14).

This method has been used primarily on our parkway projects and occasionally on our truck routes. It has worked well and after four years of service there have been no reported problems.

Some states have reported differential frost heave. The climate on Long Island is relatively moderate.

It is recommended that use of the inverted T, sleeper slab, be preceded by an investigation of the frost heave potential of the area in which it is to be used.

Method #2-- Replace the Load Transfer Device Method (Figure 15).

This method involves the removal of five feet of concrete pavement up-station and down-station from the ruptured joint; establishment of a new load transfer device at the same location of the one removed; and securing the new concrete to the existing up-station and down-station concrete pavement by means of epoxy mortared dowels.

This method has performed well after four years of service. There was one serious field application problem however.

The problem was improper installation of the epoxy mortared dowel bars.

There are many ancillary problems endemic to this operation, ranging from contractor indifference to improper design criteria.

We solved the problem through intense, close and constant field inspection [7].

Method #3-- Modified Michigan Method (Figure 16)

This method involves the removal of three feet of concrete pavement, up-station and down-station from the ruptured joint; drilling 1-3/8" holes at 12" centers, through the neutral axis of the existing up-station and down-station concrete pavement; and placing therein, 18" long, 1-5/16" diameter steel dowels. These dowels according to the Michigan design are to remain free to move within the 1-3/8" holes and be bonded within the concrete repair.

The Modification. The Michigan design is easy to execute (no epoxy mortar) and it can reduce the cost of the repair considerably (it uses 40% less concrete than method one or two).

The proposed modification is to coat the dowel bars with epoxy gel (easy to work with), place them in the 1-3/8" hole and lightly grease the bar segments to be encapsulated within the concrete repair.

This method shows great promise from the point of contractor ease of operation and appreciable extension of the rehabilitation dollar.

Conclusion:

Sound engineering judgement requires that the material and method used to repair P.C.C. buckling failures be such that pavement integrity is restored and its service life extended.

Asphalt concrete as a repair material fails to meet that criteria.

Through the judicious use of repair materials such as calcium chloride accelerated P.C.C. and re-establishment of load transfer methods such as the modified Michigan method, restoration of pavement integrity and extension of service life can be achieved expeditiously at reasonable cost.

Acknowledgements

The success of the material and method under discussion was in no small way the result of information shared with us by the aforementioned persons and organizations. To all of them we express our deepest appreciation and thanks.

The cement chemistry portion of this report was reviewed by Nate Greening and Francis Young.

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the information and data presented herein and do not necessarily reflect the official views or policies of the New York State Department of Transportation, nor do they constitute a standard specification or regulation.

References

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Figure 1. Pavement system movement as an integral unit into the non-integral full depth pavement repair of asphalt concrete. (Schematic view)

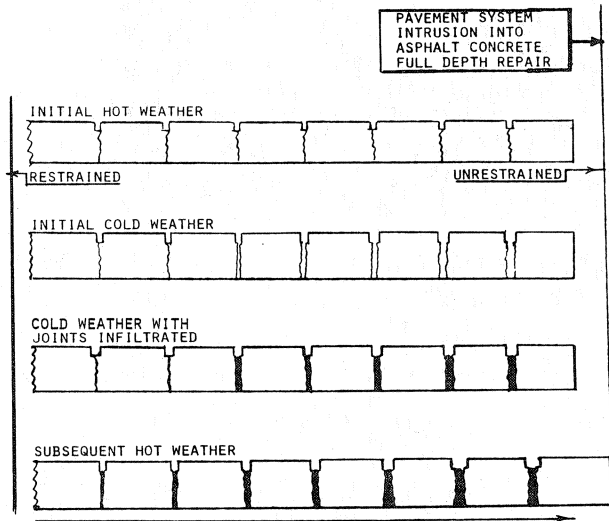


Figure 2. Condition of pavement in the area of MM 1250 on Route 27 EB, in East Patchogue, as the result of a full depth repair using asphalt concrete.

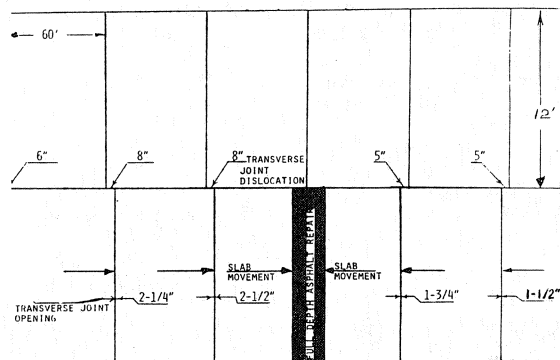


Figure 3. Convex hump in asphalt concrete repair.



Figure 4. Transverse joint dislocation due to system crushing into the asphalt concrete repair.



Figure 5. Transverse joint dislocation.

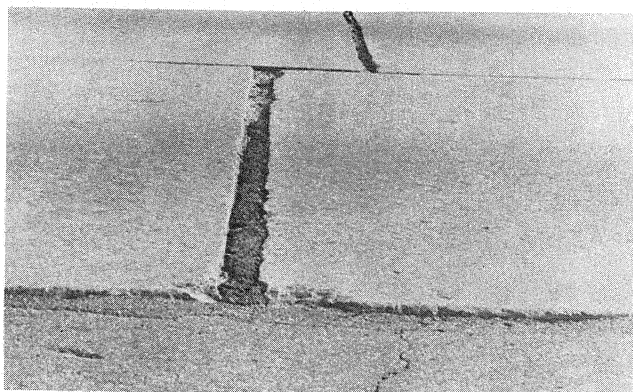


Figure 6. Longitudinal joint tie shear failure.

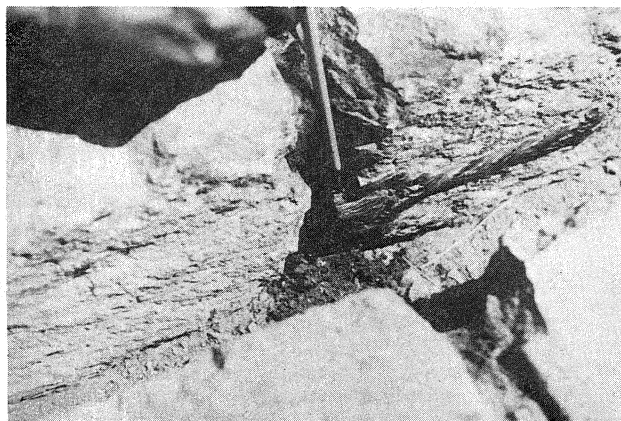


Figure 7. Longitudinal joint fault, due to shearing off of longitudinal joint ties and subsequent pavement panel slipping off of the longitudinal shear key.



Figure 8. Transverse joint fault.

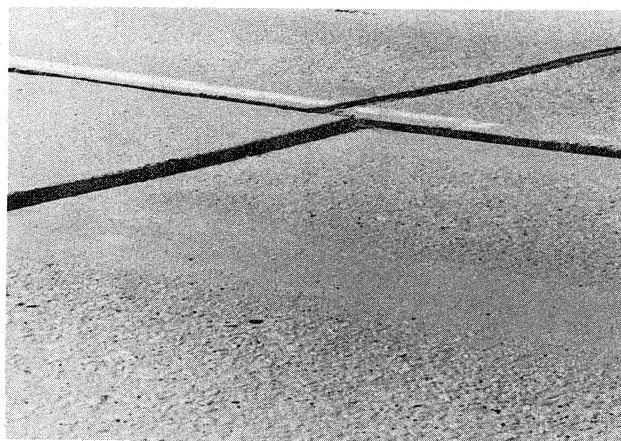


Figure 9. Rate of heat evolution plotted against time for type III cement and a water cement ratio of 0.4. (After Cooke [8])

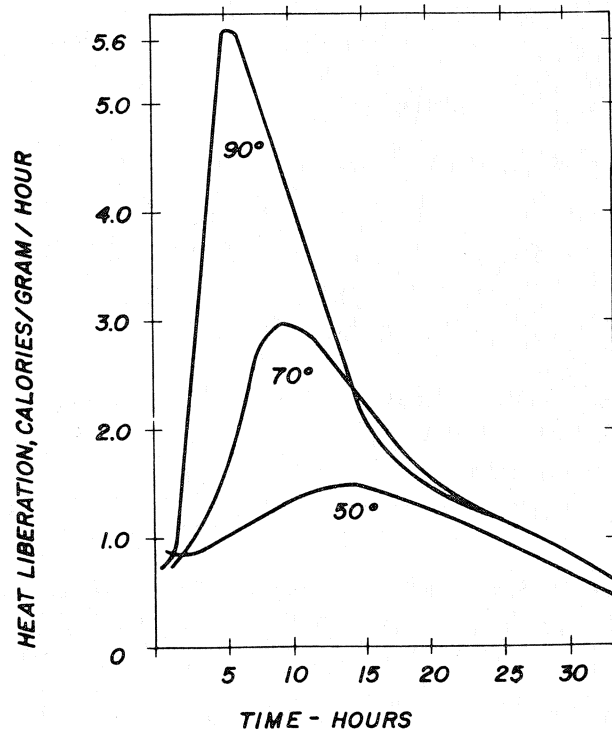
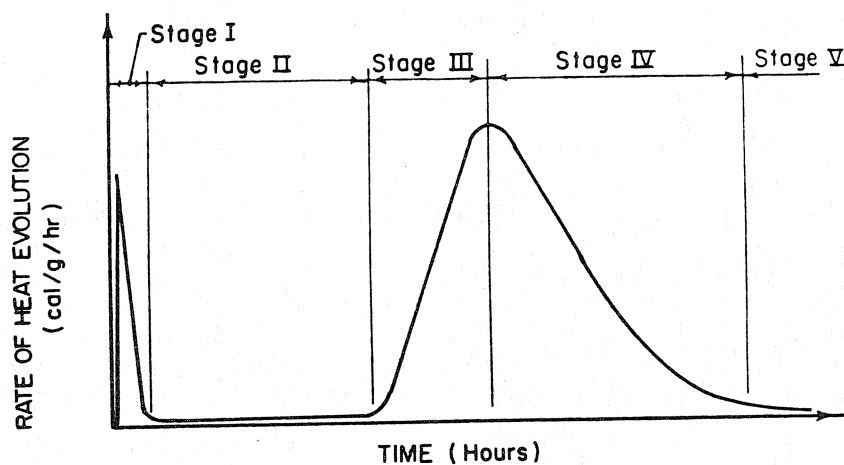


Figure 10. Heat liberation curve of hydrating C_3S as determined by isothermal condition calorimetry. (After Kondo and Daimon [9])



- STAGE I A brief initial period of reactivity, 15 minutes, then a tapering off for 15 minutes, then entry into the Dormancy Period.
- STAGE II The Dormancy Period. Two hours in length for our system, without $CaCl_2$. For a properly designed $CaCl_2$ system, such as the one under discussion, and with a discharge temperature of 90°F, the Dormancy Period is virtually eliminated.
- STAGE III The Acceleration Period, where there is renewed reaction and very rapid hydration of C_3S , formation of C-S-H gel and $Ca(OH)_2$. In the system under discussion it usually lasts 3.5 hours. Most of the C_3S is hydrated. Compressive strength is close to 3000 psi.
- STAGE IV The Deceleration period. The reaction slows down and is osmosis diffusion controlled.

Figure 11. Classification of hydration stages of C_3S , on the basis of Ca^{++} ion liberation. (After Young [5])

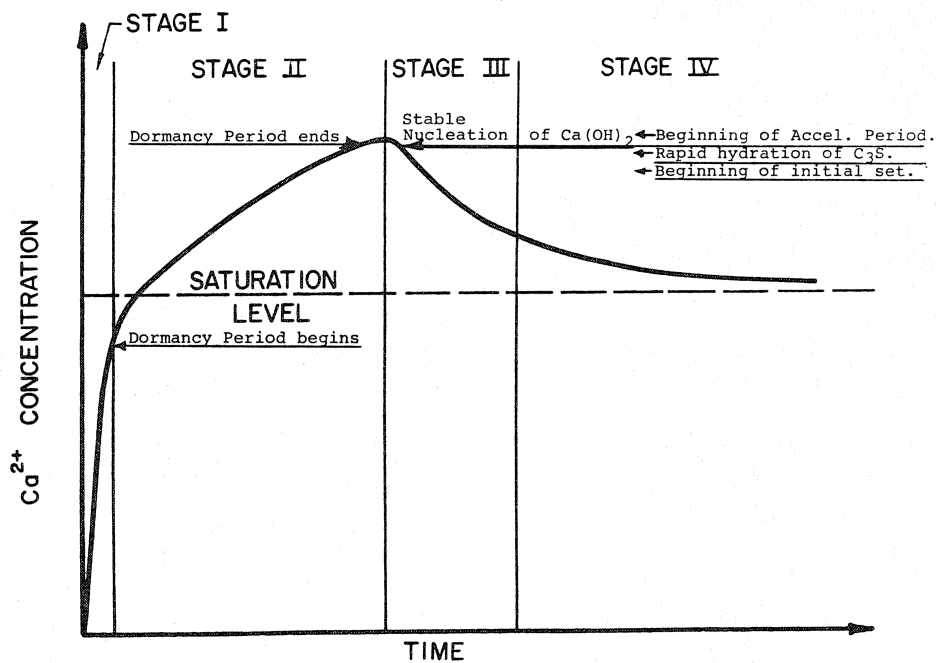


Figure 12. Juxtaposition of calcium chloride accelerated system (-----) with a normal system (—), with regard to time of Dormancy period break out. (After Young [5] and Bugler)

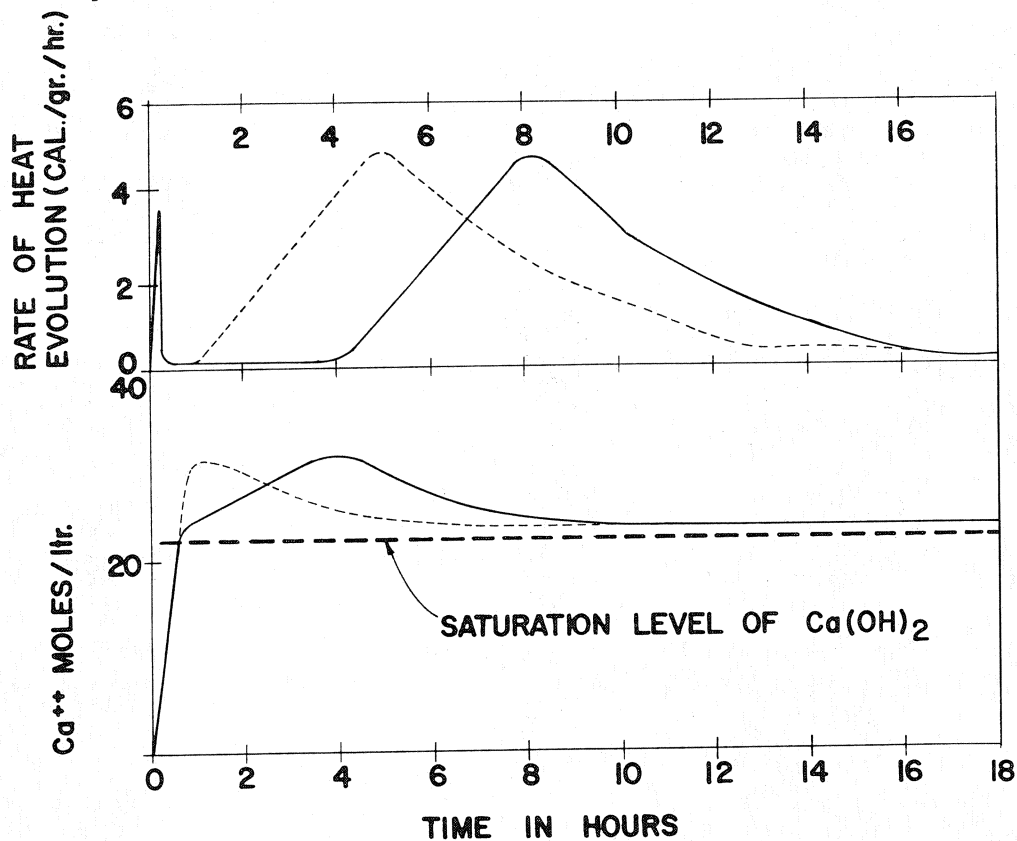


Figure 13. Concrete temperature data based on the average of 24 full depth repairs executed on Project D-96665.

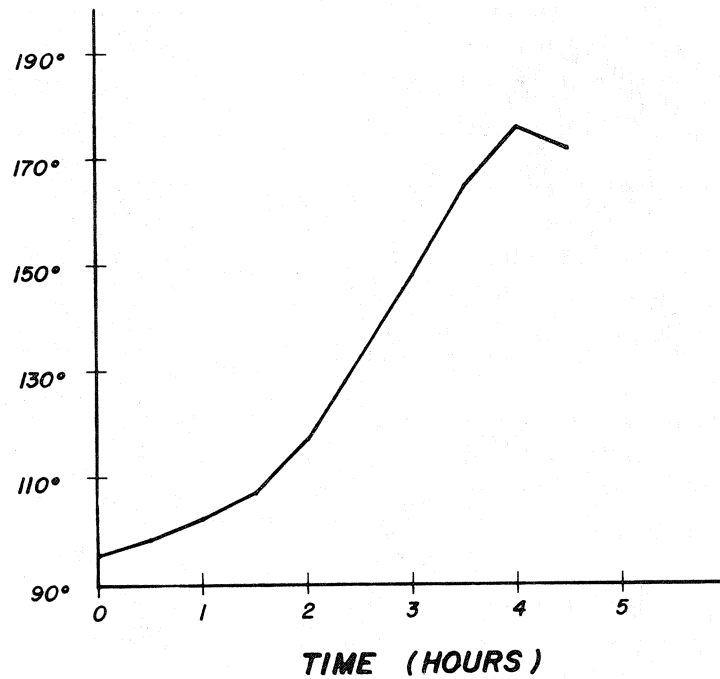


Figure 14. Inverted T Sleeper Slab Method. (full section view)

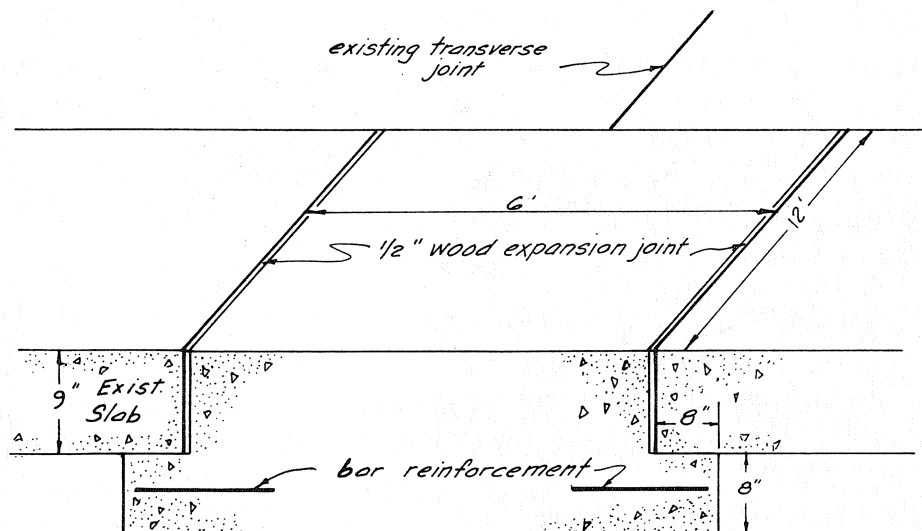


Figure 15. Replace the load Transfer Device Method. (half section view)

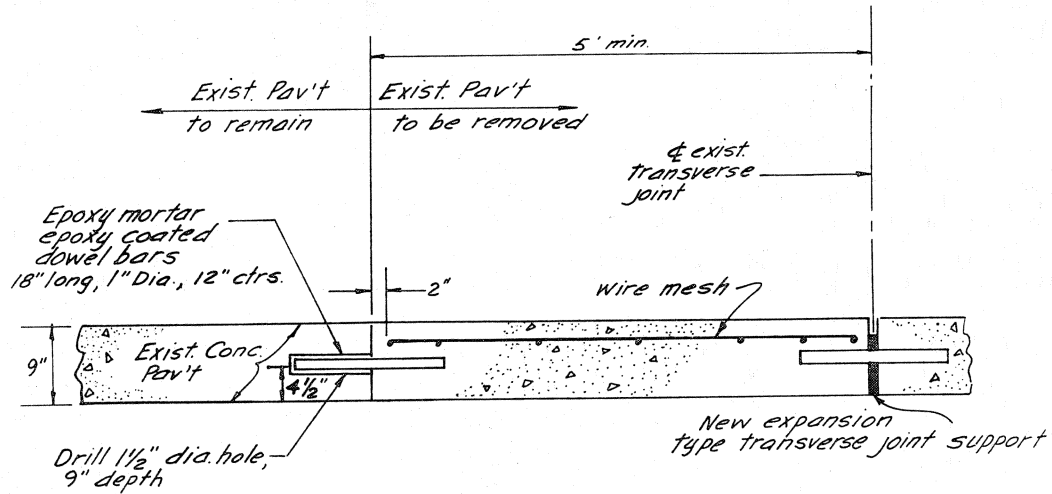


Figure 16. Modified Michigan Method. (full section view)

