THE TECHNIQUE OF STEAM CURING OF CONCRETE

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With the addition of water to portland cement two chemical reactions take place—hydrolysis and hydration. The process by which the chemical reactions are permitted to proceed by providing proper conditions of temperature and humidity is called the curing of concrete.

With the production of concrete members in factories, the problem of curing has become very acute on account of limited and costly space in the casting yards. This space, if reserved for the precast concrete members for the duration of conventional curing, will result in very uneconomic productive capacities of the casting factories.

The advantages resulting from hastening the curing process are manifold. Shuttering and moulds can be released quickly, smaller stacking areas can be used and works completed expeditiously.

Curing Methods

Curing methods mainly fall in three broad categories :

1. Prevention of evaporation by ponding, or covering the concrete with wet material.
2. Minimizing loss of water by means of an impermeable layer.
3. Keeping the concrete in moist condition and applying artificial heat.

The first method, *viz.*, ponding or covering with wet material is the conventional method and produces the best results but is an inconvenient and expensive method as comparatively more supervision, labour and time are involved.

In the second method the evaporation of water is prevented but this method is not very reliable especially when the application of covering is delayed. The impermeable layer, however, cannot be applied until the moisture on the surface has disappeared. Thus these layers cannot be applied for periods of 1 to 3 hours with the result that in hot climates a considerable quantity of water contained in concrete evaporates and there is ineffective curing.

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The third method which involves the application of artificial heat whilst the concrete is maintained in a moist condition, is adopted in the case of steam curing. This process is applied when accelerated curing is desirable. For the purposes of this accelerated curing there are two essential requirements.

1. There should be no elevated temperatures:
2. The products should be prevented from drying.

The process of Steam Curing which can meet the above requirements can be classified into three categories :—

1. Intermittent low pressure curing.
2. Continuous low pressure curing.
3. High pressure intermittent curing.

In the first process the products are stacked in a chamber and then the steam is admitted. In the continuous process the products move in the chamber already filled with steam on belts or trolleys. In the third process the products are stacked in a chamber which is then securely closed and the steam is admitted at high pressure.

The first process, namely, intermittent low pressure steam curing, will be discussed in detail in this paper. This is the process which was adopted at the two new prestressed concrete bridge sites at Jhelum and Lahore.

Experiments have revealed that the concrete products cured with low pressure steam curing behaves in exactly the same manner as conventionally cured concrete in the case of strength and shrinkage. Another advantage in this process is that rapid temperature rises and rapid cooling do not result in any cracking due to differential stresses.

The only important point to be observed in the case of low pressure steam curing is that the initial rise in temperature should never be too rapid. A temperature of 50°C. must not be exceeded during the first $1\frac{1}{2}$ to 2 hours and a temperature of 100°C. must not be attained before 5 to 6 hours. If this precaution is not observed and there is a too rapid initial rise in temperature the result is increased strength during the first few hours, but there is a loss of ultimate strength which may be as much as 30 per cent.

Only when a high early strength at the sacrifice of ultimate strength is required, a rapid early rise of temperature may be adopted.

The temperature rise of the concrete lags behind that of the chamber in the early stages, but gradually gains on the latter until equilibrium is reached at about 70°C. to 80°C. At this point the steam is shut off and the temperature allowed to fall slowly.

The maturity of concrete may be defined as the product of the number of hours elapsed since pouring and the average temperature above freezing which has been maintained. This maturity is conveniently expressed in the unit of °C hours. The laboratories have usually a curing tank controlled at 16.66°C. Thus 24 hours curing will give a maturity of $16.6 \times 24 = 4000°$ C-hour. For 7 days curing, this figure will be 2,8000° C-hour and for 28 days curing it will be 11,2000° C-hour. Experiments have shown that this unit of maturity will be the same for normal curing as well as for steam curing. Thus if the maturity required to produce a given strength with a given mix with normal curing is known or is found by trial, it is possible to decide what heat treatment will be required to attain the same strength in a given shorter period.

Figure 1 shows the gain in strength plotted against the age when the temperature is controlled at 16.6°C. The curve also shows the strength achieved against the maturity in °C hour which will hold good for the particular mix whatever combination of temperature and time is adopted.

FIGURE 1: GAIN IN STRENGTH OF CONCRETE WITH MATURITY

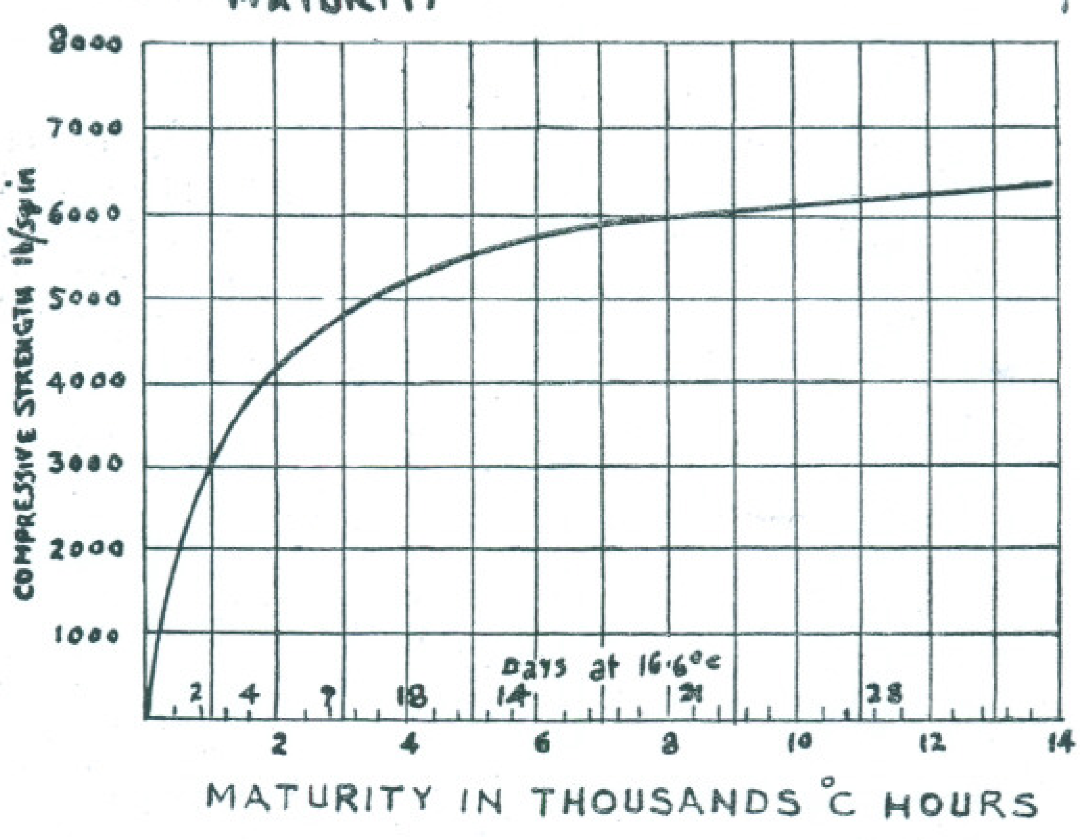


Figure 2 shows the critical temperature gradient which must not be exceeded if proper results are to be achieved.

FIGURE 2 CRITICAL TEMPERATURE GRADIENT

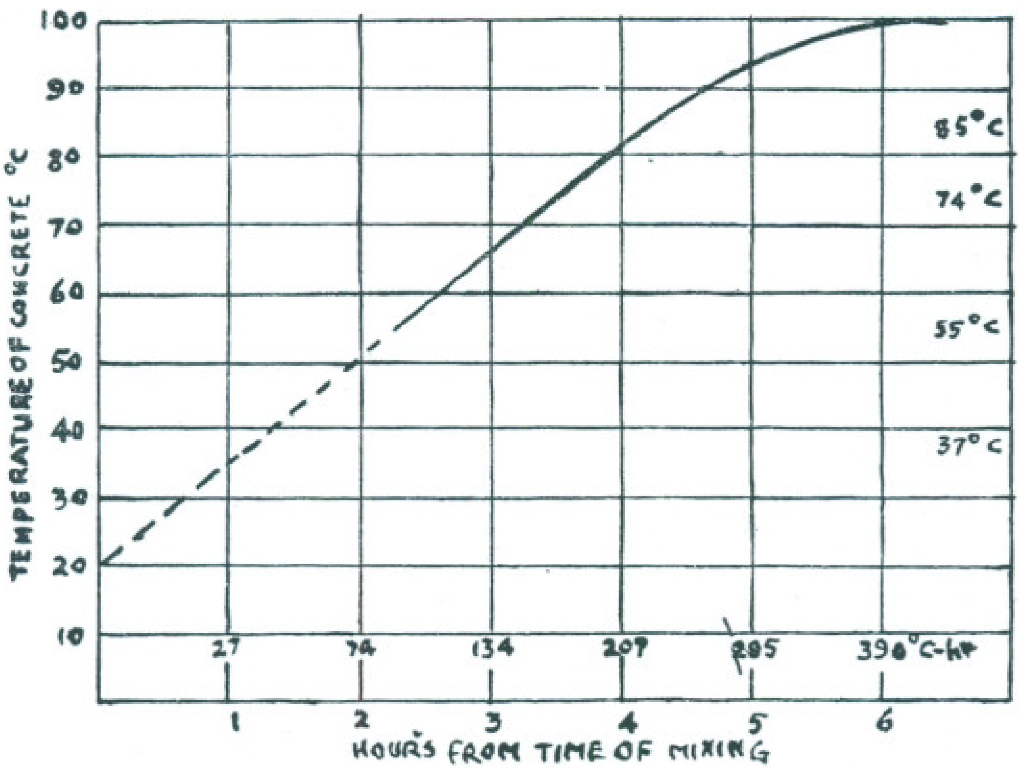


Figure 3 shows the temperature of concrete and of the curing atmosphere throughout experiments carried out in a laboratory on two specimens. The temperature of the concrete at first lags behind that of the curing chamber but soon rises due to the heat generated by chemical reactions in concrete. The temperature of concrete remains higher than that of the chamber during the cooling period but never rises atbove 100°C due to the evaporation of moisture. The temperature of the concrete product and not that of the chamber matters in the control over the curing treatment. As the temperature of concrete will not rise above 100°C, the temperature of the curing chamber need not be raised above the limit which will produce a temperature of 100°C in the concrete product.

In the treatments under review, shown in Figure 3, in the case of specimen A the steam was shut off after $5\frac{1}{2}$ hours and in the case of B it was shut off after $13\frac{1}{2}$ hours. Thus a maturity of 1510°C hour was imparted to A and of the order of 1910°C to B. Comparing with the normal curing process, A gained a strength of $3\frac{3}{4}$ days normal curing and B gained the corresponding strength of $4\frac{3}{4}$ days. The difference in strength was 10 per cent.

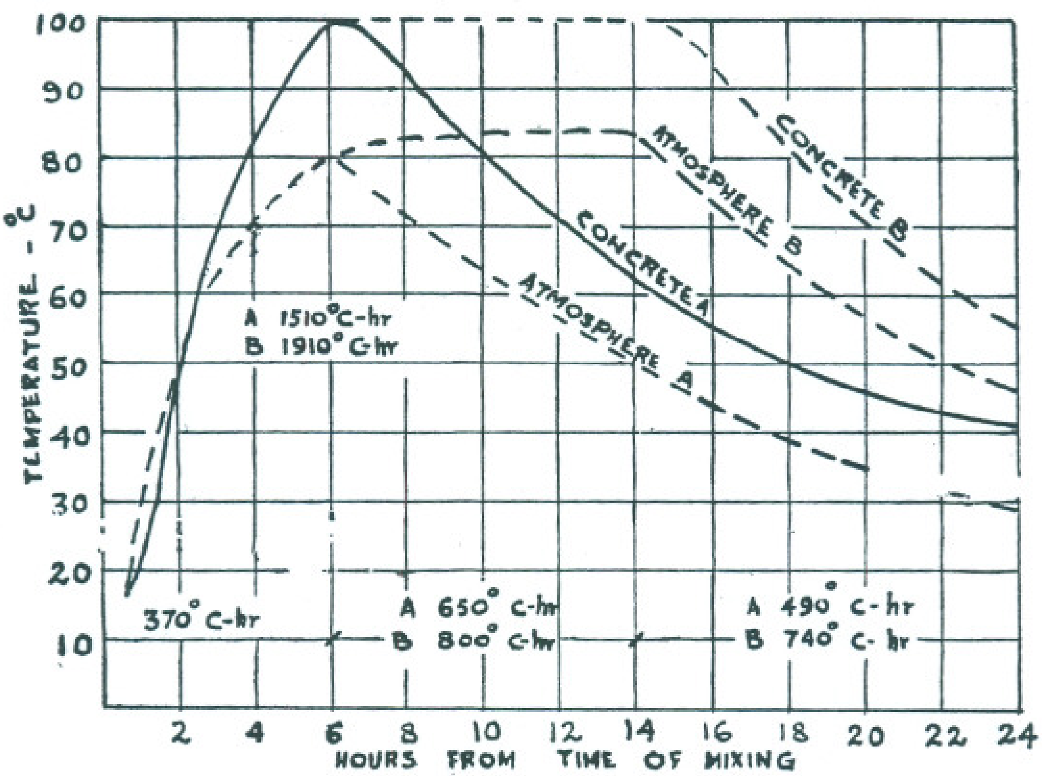
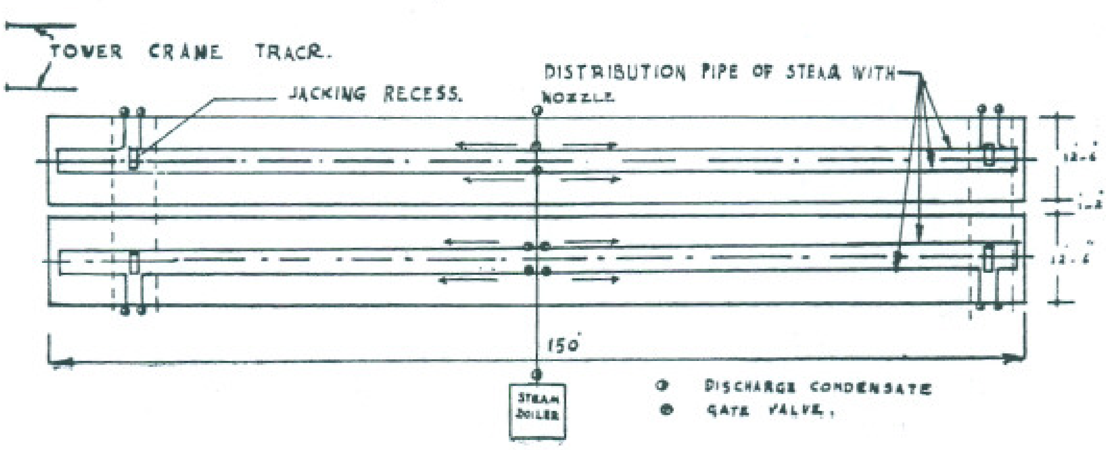


FIGURE 3: TEMPERATURE OF CONCRETE AND OF ATMOSPHERE DURING STEAM-CURING TREATMENT.

FIGURE 4 GENERAL ARRANGEMENT FOR STEAM CURING (JHELUM BRIDGE)

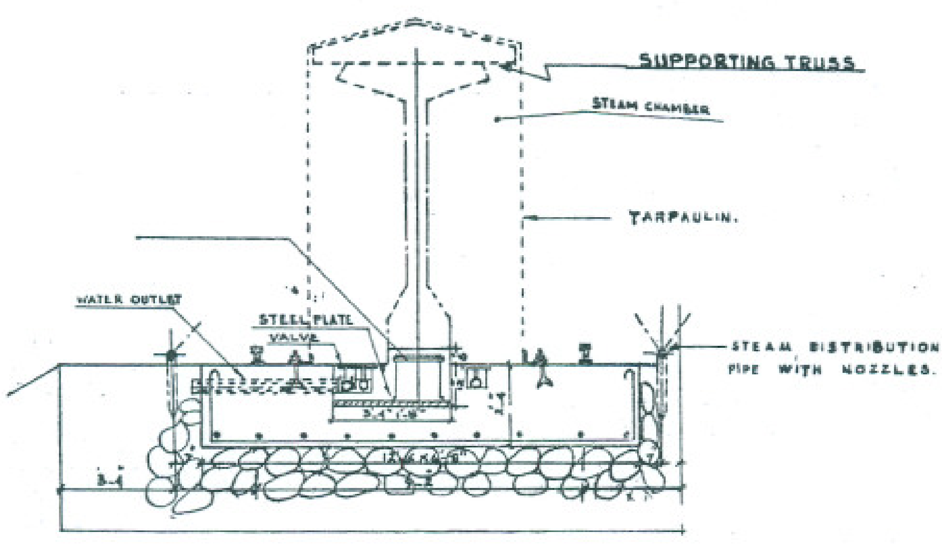


Thus given the required strength and the allowable time for curing, a schedule can be planned within the limits imposed by time and the temperature range.

At Jhelum M/s Mantelli Estero Construzioni, the bridge contractors had to produce 88 prestressed concrete girders each about 147 feet long. For this purpose they made two beds of the type shown in Figure 4. For Generation of steam a Lancashire type vertical boiler was used. For circulation of steam 1″ diameter G.I. pipes were laid around the beds. Perforations were made in the pipes for introducing steam.

Instead of making a proper steam chamber the contractors adopted the method of stringing tarpaulines over the concreted girders. These tarpaulines were securely—fastened with strings looped through hooks already laid in the casting bed. Supporting trusses as shown in Figure 5 were placed on the shuttering to facilitate circulation of steam.

FIGURE:-5 SECTION THROUGH STEAM ARRANGEMENT
(JHELUM BRIDGE)



Six thermometers were installed in this chamber to observe and control the temperatures.

The recommendations laid down by the National Association of Italy for prestressed Reinforced Concrete (A.N.I.C.A.P.) were observed in this process. These recommendations are reproduced below :—

Stage I. A waiting period of one to three hours after the concrete has been poured. This ensures some stability to the product due to the *initial* stages of chemical reaction in cement.

Stage II. In this stage the product is heated up gradually by introducing steam. The duration of this stage may vary between 1 and 6 hours. The rate of temperature increase should not be allowed to exceed 20°C per hour.

Stage III. During this stage which extends over a period of 12 to 18 hours, the temperature is kept constant at the maximum value which varies between 50°C and 70°C.

The steam curing treatment should never be extended beyond these limits as otherwise the final strength will be adversely affected.

Another important precaution laid down by the National Association of Italy for Prestressed Reinforced Concrete relates to the control over the cooling of the product. The cooling has to be gradual and normally natural cooling to the atmospheric temperature is practicable but when the atmospheric temperature is too low, the product should not be allowed to cool down too rapidly.

If with steam curing the strength achieved is 70 to 80 per cent of the final value, wetting for further curing is not necessary, but if after the steam treatment the strength is 50 per cent of the final strength, normal water curing may be resorted to.

Based on these recommendations the following specifications were approved by the Consulting Engineers :—

Stage I. The first stage of waiting period of two hours after the completion of casting. Evaporation to be avoided by covering with wet hessian.

Stage II. The second stage of two hours with the temperature of steam not exceeding 20° C.

Stage III. The third stage of six hours with the temperature varying from 50°C to 70°C. This temperature to be attained slowly.

Stage IV. Steam to be shut off and the beams allowed to cool down to atmosphetic temperature in a period of two to four hours.

Stage V. After cooling the concrete surface to be protected from direct sun for a minimum of forty-eight hours so that surface does not dry out rapidly.

The designed strength of concrete was 6000 lb/sq. inch after 28 days of normal curing and the strength required for the first stage of stressing was 4000 lb/sq. inch. After completing the above stages of curing with steam, the strength attained was more than these requirements in all cases.

In order to compare the strength achieved with normal water curing with that achieved with steam curing, a record of the crushing strength of the cubes cured with the two methods was maintained continuously. Table I giving the comparison of a few batches is given below:

TABLE 1 COMPARISION OF CRUSHING STRENGTH
(JHELUM BRIDGE)

BEAM No:	CRUSHING STRENGTH AFTER 1 DAY		CRUSHING STRENGTH 7 DAYS	
	WATER CURING 1 DAY	STEAM CURING 12-14 HOURS	WATER CURING 7 DAYS	STEAM CURING 12-14 HOURS
16	4050	6200	7550	6750
17	3400	5400	6850	6350
18	2550	6100	6750	6550
19	4000	5650	7950	7550
20	1875	4825	7050	6900
21	2200	5100	7350	5950
22	2550	5375	7350	6500
23	2850	5775	6750	7050
24	3100	6750	7350	6275
25	2025	5375	7000	6400
26	2100	5900	6675	6500
27	2075	5050	6625	6500
28	2250	4925	5980	6 50
29	2475	5650	6500	6100

The technique of steam curing was used for the prestressed girders of the new Ravi bridge as the time for casting of the beams was very short and it was necessary to cast at least one beam daily. At this site a steam chamber of the type shown in figure 6 was constructed. It had concrete pillars and brick walls. The pillars were provided to support the shuttering after it had been dismantled and placed leaning against the side of the steam chamber. To supply steam a boiler of the type Ten Horn, V5, manufactured in Holland, was installed. Steam was circulated in the chamber by means of 1″ diameter G. I. pipes fixed at a height of 3 feet above the floor of the chamber. The pipes had perforations at 1 foot intervals. The roof of the chamber was closed with wooden planks which could be removed for shifting of the finished beam and for placing reinforcement for a new beam.

As a precaution against the adverse effect of steam curing on the final strength of concrete, the mix was redesigned to give a strength of 7,000 *psi* after full curing.

During tests with the empty chamber it was realised that this particular boiler could not keep the chamber at the required maximum temperature.

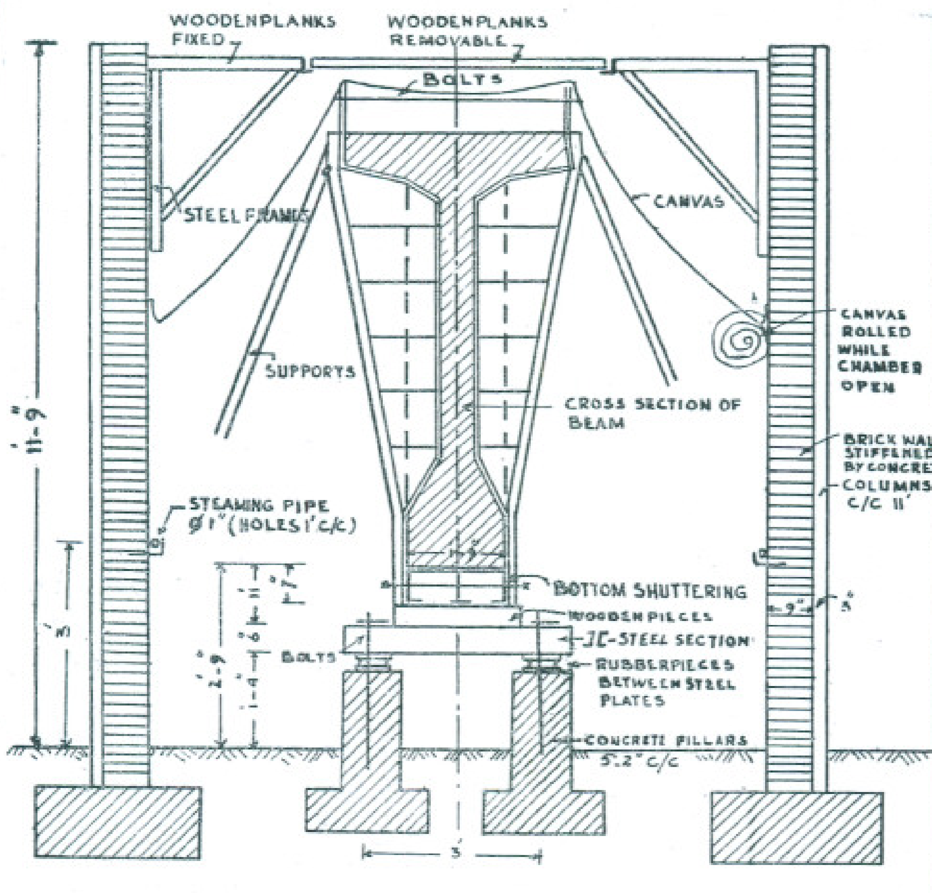


FIGURE:-6 STEAMING CHAMBER (RAVI BRIDGE)

SCALE:- ½" = 1'

The volume of the chamber was therefore reduced by canvas cover as shown in Figure 6. Moreover the air between this canvas and the wooden planks added to the insulation effects. The beams and shuttering also reduced the volume by about 10 per cent. Finally the capacity of the boiler was sufficient.

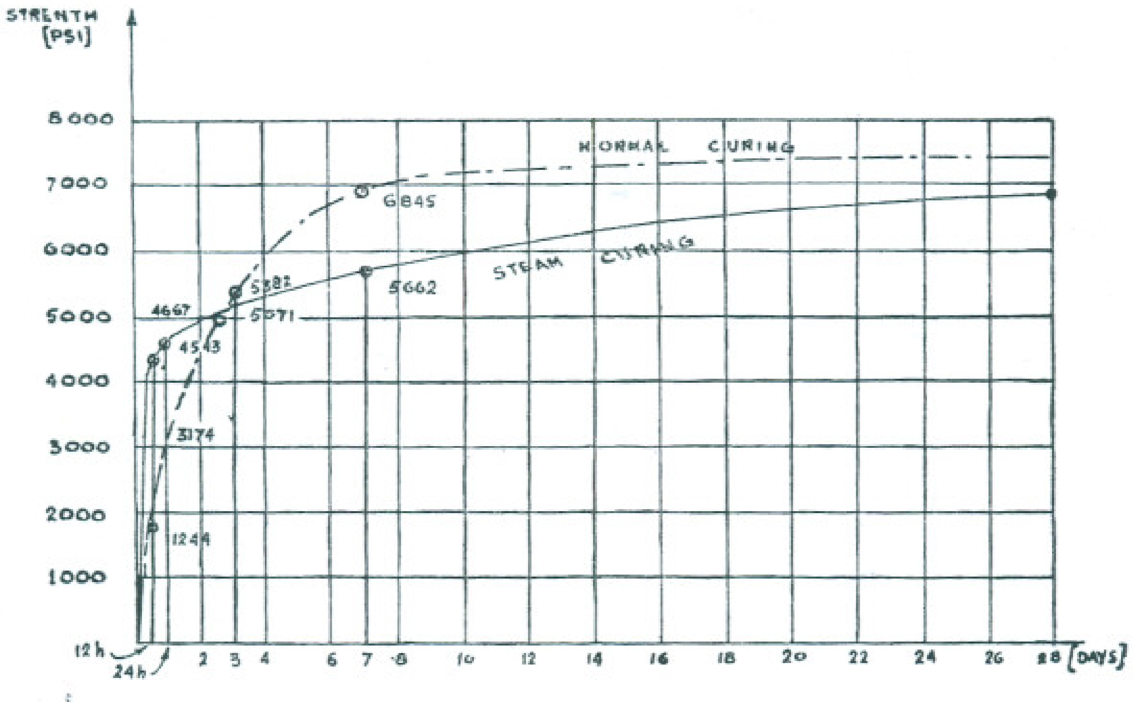


FIGURE 7: COMPARISON BETWEEN STEAM AND NORMALLY WATER CURED CONCRETE CUBES. (ALL CUBES HAVE BEEN CAST OUT OF THE SAME MIX AND AT THE SAME TIME.)

In order to gauge the efficiency of the process, tests on 12 cubes were carried out. Figure 7 shows the comparisons between steam and water cured concrete cubes. The rapid increase in strength during the first 12 hours is clearly visible. The difference in strength after 28 days was 9.6 per cent only. The following schedule was observed for this test :—

1. Delay period of 2 hours.
2. Heating period of 2 hours 20 minutes.
   The rate of increase of temperature to be 25°C/hour.
   The atmosperic temperature was 20°C and the maximum to be attained 80°C. Thus a period of 2 hours 20 minutes was required.
3. Period of constant temperature 4 1/2 hours.
4. Cooling period 2 hours 20 minutes.
   The rate of cooling was 25°C per hour.
5. Waiting period before testing the cubes from 1 to 2 hours.

The maturity according to this proposed cycle worked out to 654°C hour. Actual measurements during the test gave a figure of 706°C hour.

After carrying out tests on cubes cured by the steam in the chamber the following time schedule was laid down as shown in Figure 8.

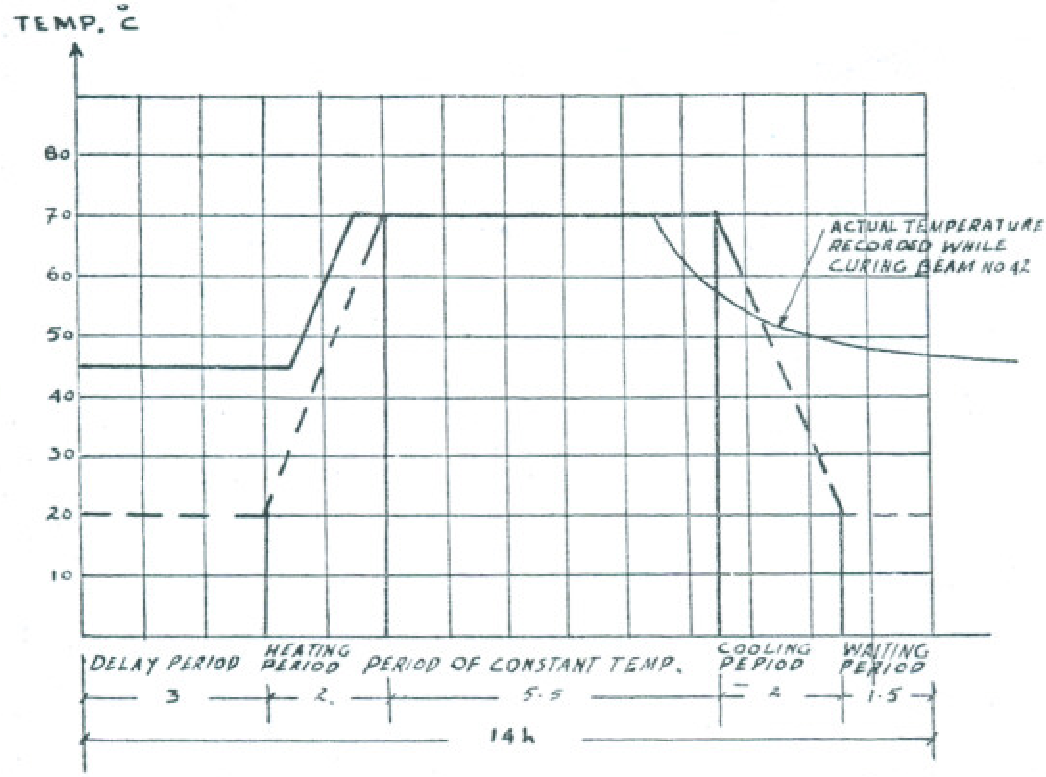


FIGURE 8 PROPOSED CYCLE OF STEAM CURING OF THE BEAMS & ACTUAL MEASURED TEMPERATURES OF BEAM NO. 42 (RAVI BRIDGE)

Stage I. A delay period of 3 to 3.5 hours. Originally in the tests a delay period of 2 hours was tried with good results but test results on the cement revealed that the particular quality of cement being used on this work had an initial setting time of about 2½ hours. The delay period was therefore extended from 2 hours to 3-3.5 hours.

Stage II. A heating period of approximately 1½ hours was required depending on the time involved in reaching 70°C from the atmospheric temperature. The atmospheric temperature was between 30 to 38°C. The rate of increase in the temperature was 25°C per hour.

Stage III. A period of constant temperature of 70°C for 5-5½ hours.

Stage IV. A cooling period of 2 hours. In this stage the girders were allowed to cool down to the atmospheric temperature which was between 30 and 38°C.

Stage V. A waiting period of 1½ hours.

A comparison of the curing schedule laid down for Jhelum and Ravi Bridge Beams reveals that it in principle the specifications were the same. The main difference however was in the total curing period which could be chosen longer in case of Jhelum Bridge as compared to Ravi Bridge. The temperatures at Jhelum Bridge could be kept lower for obtaining the same maturity whereas in the case of Ravi Bridge the tight schedule required shorter periods and therefore higher average temperatures. But in both the cases the maximum temperature did not exceed 70°C. In both the cases approximately the same results were achieved for the specified strength. However, lower results for steam cured concrete as compared to conventional curing have been recorded. For this characteristic, suitable provision was made in the design of the mix for obtaining the required strength of 6000 lbs. *psi* after 28 days. In case of Ravi Bridge the final strength of 7000 lbs. *psi* was designed.

Out of the 72 beams for the new Ravi Bridge 61 were steam cured. A record of temperature for every beam was maintained. Figure 8 shows the recorded temperature for beam No. 42.

Table No. 2 indicates the curing time, maturity, strength at the time of first stressing and the 28 days' strength for some beams. In the case of the steam cured beams of the Ravi Bridge it was found that the stressing of the first stage could be done after 13 to 14 hours whereas in the case of normal curing it had to be done after 32 to 40 hours.

The two successful experiments carried out at Jhelum and Ravi have opened a new field for this technique in Pakistan by which considerable saving in time in the completion of development projects can be effected. The method and details described above are applicable in general for future projects. In individual cases tests will have to be carried out on the lines explained in the foregoing pages, to determine the maturity for a given compressive strength.

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4. Mr. Riaz Ahmad, Superintending Engineering, Aided Projects (Highway Department), Lahore.
5. Mr. Muhammad Akhtar Qureshi, Executive Engineer, Jhelum Construction Division, Jhelum.

TABLE 2 PREFABRICATED MAIN BEAMS OF NEW RAVI BRIDGE NEAR LAHORE

BEAM NO	DURATION OF CURING CYCLE	MATURITY	STRENGTH FOR STRESSING	28 DAYS STRENGTH
	(H)	°CH	(PSI)	(PSI)
1	47	NO STEAMING	4863	7467
2	17.5	861	4074	6886
3	18.5	916	4086	6554
4	19.5	953	5517	6906
5	35	NO STEAMING	4708	7467 x)
6	43	NO STEAMING	4480	6969
7	43	NO STEAMING	4480	7467 x)
8	15.5	721	4168	6782
9	22.5	1028	5123	6720
10	71	NO STEAMING	6450	7467 x)
11	44	NO STEAMING	5102	7467 x)
12	43	NO STEAMING	5019	7467 x)
13	45	NO STEAMING	4252	7467 x)
14	20	1031	4418	6845
15	20	1129	4667	6886
16	14	792	4521	6658
17	13.5	795	5251	7051
18	15	872	3982	6844
19	14.5	816	4450	6181
20	13	781	4729	6679
21	32	NO STEAMING	4584	7467 x)
22	14	842	5144	7155
23	13.5	818	4252	7135
24	21	1167	4874	6948
25	13	761	4065	6699

x) CUBES DID NOT CRUSH, BECAUSE THE CAPACITY OF THE CRUSHING MACHINERY WAS LIMITED UPTO 120 T, WHICH MEANS 7467 PSI FOR 6 INCH CUBES

1	2	3	4	5
26	37.5	NO STEAMING	4272	7384
27	13.5	754	4355	7239
28	13	766	4314	6803
29	13	751	4189	7280
30	14	812	4501	7301
31	13.5	765	4106	7073
32	13.5	759	4356	7467 x)
33	13.5	772	4335	6844
34	13.5	785	4314	6844
35	13	782	4314	6679
36	12.75	807	4189	6513
37	13.5	802	4623	6844
38	13	772	4127	6782
39	13.5	811	4625	7259
40	13.5	802	4189	6865
41	13.5	811	4273	7280
42	14	848	4729	7155
43	20.5	1212	4625	6948
44	13.5	892	5040	6596
45	13.5	909	4055	6575
46	13.5	843	4107	6845
47	14.5	902	4210	6844
48	13	784	4335	7279
49	13.5	774	4480	7259
50	13	731	4625	7446
51	13	767	4708	7467
52	14	823	4687	7321
53	13.5	821	4314	6907
54	14.5	863	4345	6347
55	14.5	893	4210	6927
56	16.5	962	4252	6386

1	2	3	4	5
57	13·5	830	4753	7259
58	14	865	4732	7135
59	14·5	923	4396	6927
60	14	863	5060	7446
61	13.5	849	4397	7197
62	14	878	4107	6990
63	13·5	863	4107	7176
64	13·5	869	4024	6699
65	13·5	834	4169	7031
66	14·5	904	4418	6574
67	14	889	4169	6824
68	16·5	864	4044	6637
69	13·5	850	4314	6844
70	13·5	827	4418	6741
71	14	832	4337	7280
72	63	NO STEAMING	6202	7467 x)

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