SOME PECULIARITIES OF CONCRETE TECHNOLOGY IN THE CONDITIONS OF HOT HUMID CLIMATE OF VIETNAM

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SUMMARY

The paper presents some peculiarities of concrete technology in the conditions of Vietnam Hot Humid Climate and working state of concrete structures situated in the local climatic conditions. Some results of the study of the author and colleagues during about 20 recent years in the fields of concrete and concrete technology (concreting, processes of concrete hardening, curing, and deformation of concrete and concrete structures) in the climatic conditions of Vietnam are introduced in the paper.

PECULIARITY OF THE PROCESS OF CONCRETE HARDENING IN THE CONDITIONS OF HOT HUMID CLIMATE

During the process of concrete hardening under the action of Hot and Humid Climate (HHC) there have a series of happened physical processes, such as: processes of water loss and plastic deformation, formation of porous structure and initial structure of concrete, appearance of surface cracks and so on [1-4]. Hereinafter is introduction of some the results of studying them in Vietnam

Process of water loss of concrete

Studying shows that under the action of HHC conditions (such as: solar radiation, wind, rain, air temperature and humidity) concrete loses its mixing water right after finishing the surface of concrete structures (Figure1). The process of water loss of concrete has the following characteristics:

- Beginning water loss right after finishing of surface of structures
- Loss of 40-60 % initial mixing water after 4-6 h of concrete hardening
- Duration of water loss is 4-6 first days of hardening (Table 1)
- Formation of porous structure (Figure 2)
- Causing plastic deformation of concrete

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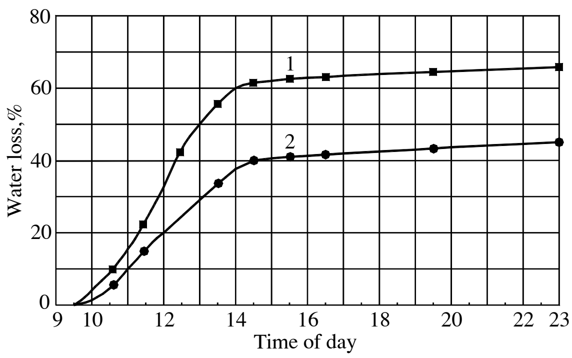
The factors that influence on the process of water loss of concrete may be listed as intensity of solar radiation, air humidity, wind velocity, climatic season and so on.
The study shows that concrete may loses 60-63% of initial water at the day having strong sun light, while at the day of low sun light- loses only 29-52% of water.



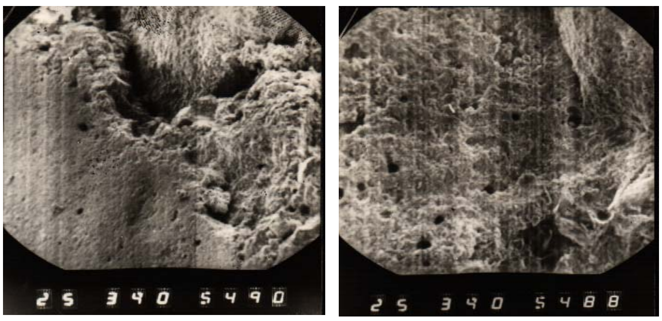
1- Mh = $30m^{-1}$
2- Mh = $10m^{-1}$
N/X = 0.46
Climatic conditions:
*Solar radiation: Q = 700- 800 Kcal/m2.h
*Air temperature: T = 33-35 ^{0}C
*Air humidity: φ = 80-95%
*Wind velocity: ν = 0, 2- 0.8m/s

During a day in Summer in Hanoi

Figure 1- Process of water loss of concrete

Table 1 Duration of water loss of concrete in HHC

N/X	Water loss of concrete after drying days under sunlight								Mh
	1	2	3	4	5	6	7	8	
0.65	60.7	73.3	74.0	76.1	77.4	77.8	78.0	78.5	$25m^{-1}$
0.55	50.8	59.5	62.2	64.6	64.6	68.1	68.6	66.2	
0.45	46.8	50.7	51.3	52.5	52.6	52.9	52.9	55.8	



a) Without moist curing b) With moist curing
Figure 2 Porous structure of concrete due to water loss

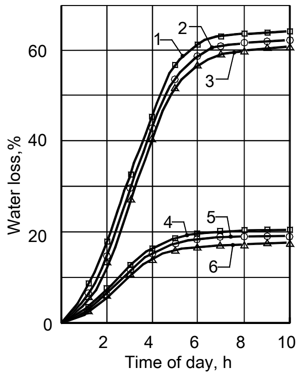
At the day in summer with air humidity 40-60% concrete (with W/C= 0.37-0.54) loses 40-60% of water depending of W/C ratio, while with the air humidity 86-93%- loses only 32-37% of water.

Figure 3 shows that after 6h of hardening at the day in summer concrete loses 40-60% of initial water, while in winter- loses only about 20% of water. It may be explained that the high solar radiation and air temperature in summer strengthened process of water loss of concrete. It means that covering concrete surface for prevention of water evaporation is necessary in summer.

Process of plastic deformation

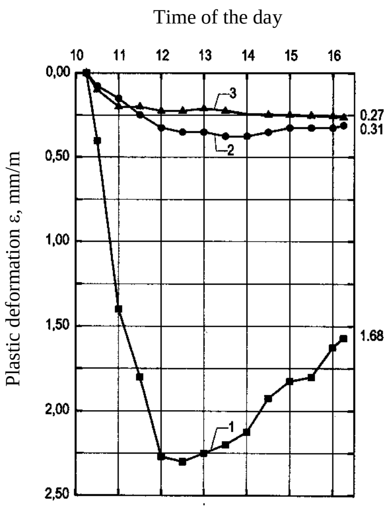
Plastic deformation is the process of volume change of concrete (shrinkage or expansion) when it has no strength or is being in plastic state.

Water loss process causes a negative pressure in concrete body that makes changing its volume. In the HHC conditions the volume change of concrete consists of plastic shrinkage and expansion (Figure 4).



1,2,3- In summer, W/C = 0,57; 0,46; 0,37
4,5,6- In winter,   W/C = 0,76; 0,61; 0,46

Figure 3 Water loss of concrete according to time of seasons



1 - Specimens with $M_{exp} = 30\ ^{m-1}$.
2 - Specimens with $M_{exp} = 0$.
3- Specimens in the room conditions. ($t = 31\ ^0C$,
$\varphi = 98 \div 100\%$, $M_{exp} = 30\ ^{m-1}$).
The weather: $t = 33 \div 35\ ^0C$.
$\varphi = 62 \div 75\%$;
$v = 0.1$ m/s
$Q_{max} = 762$ kcal/m^2.h.

Figure 4 The change of plastic deformation of concrete at time of day

The process of plastic deformation of concrete in the conditions of HHC has the following characteristics:

- It take place right at the first minutes of concrete hardening;
- Including shrinkage and expansion;
- Maximum value of plastic shrinkage may reach 3-4mm/m, and plastic expansion- 0.5-0.8mm/m depending on climatic conditions;

- Process of plastic deformation consists of 5 periods: Beginning of shrinkage; rapid shrinkage; slow shrinkage; expansion and then stabilization.
- Plastic deformation may cause some surface cracks in concrete structures (Figure 5).

Although plastic deformation takes place only for some first hours of concrete hardening it may reduce its remarkable value of compressive strength: After 4 hours situated under sun light at a day in summer concrete loses 20-30% compressive strength at the age of 28 days (R_{28}), depending on maximum value of plastic deformation ε_{max} (Table 2).
The above aspects show that curing concrete right after concreting in the conditions of HHC is very importance.

Figure 5 Surface cracks of concrete structures due to plastic deformation

Table 2 Influence of plastic deformation on 28 days' strength, $R_{28,}$ of concrete

W/C	After 2.25h under sun light			After 4h under sun light		
	ε_{max} , mm/m	Water loss W, %	Compressive strength, % R_{28}	ε_{max} , mm/m	Water loss W, %	Compressive strength, % R_{28}
0.750	0.73	46	137	0.60	57	80
0.625	1.20	30	100	0.80	59	75
0.460	2.90	29	77.7	2.60	53	70

Moist curing of concrete in HHC conditions

Moist curing of concrete is an importance stage of concreting process in Vietnam. Without it concrete may lose a part of strength at the age of 28 days. Table 3 shows that in summer, concrete may lose 9-35% of its compressive strength at the age of 28 days, depending on W/C ratio and Module of exposure M_{exp} of concrete [1].

Table 3 The loss of compressive strength of concrete on missing of moist curing

W/C	M_{exp}, m^{-1}	Loss of compressive strength of concrete at the age of 28 days on missing of moist curing, % of the designed strength		
		In May	In June	In July
0.68	10	9	13	12
	30	14	21	16
0.55	10	-	16	14
	30	23	33	27
0.44	10	-	15	15
	30	-	35	29

Basis of moist curing process

Moist curing process consists of 2 periods: The initial and continuous periods.

The initial period is the duration of time of caring concrete by covering with some wet material or an membrane for preventing water of concrete from evaporation to atmosphere. The duration of this period is about 4-7h depending on the seasons in concreting area.

The continuous period is begun right after finishing of initial one and prolongs for some first days of concrete hardening. During this period concrete surface should be kept in wet state by continuously sprinkling water on it. The continuous period is characterized by the so call **Critical strength** and **Essential time** of curing. These are the key parameters of moist curing process. The study of curing concrete in Vietnam was made by author and colleagues for a long time for determination of those parameters. And then a map of curing of concrete was established.

Zone map of curing for concrete

Since the weather is different for seasons and areas of the country the study of curing processes was made in various areas and seasons for some years from the North to the South of Vietnam. After treating data of the study the critical strength and the essential time were grouped into 3 zones of curing (A, B and C) according to characters of geography location. The zone map of curing was established for concrete technology in Vietnam. Every zone is characterized by two seasons with various values of Rcr and Tess (Table 4). From the Table 4 we can see that the Critical strength and the Essential time are increased according to the seasons Summer and Dry from the North to the South (50-55%; 55-60%; 70%) and (3; 4; 6 days) correlatively. On the contrary, they are decreased according to the seasons Winter and Wet from the North to the South of Vietnam. Practices in Vietnam show that the zone map of curing is good suitable to climatic conditions in Vietnam.

The results of study were used for development of the Vietnamese standard TCVN 5592:1991[5]. This standard provides the requirements of moist curing concrete according to Rcr and Tess for every season of 3 zones of curing.

Table 4 Characteristics of zone map of curing according to Critical strength and the Essential time of concrete

Zone map of curing	**Zones**	**Seasons**	**Months**	**Rcr,** $\%R_{28d}$	**Tess,** days
	A	Summer Winter	IV – IX X - III	50-55 40-45	3 4
	B	Dry Wet	II – VII VIII - I	55-60 35-40	4 2
	C	Dry Wet	V – XI XII - IV	70 30	6 1

Concreting of massive concrete structures in HHC

Conditions for considering a massive structure

There are two following parameters used for considering a structure as a massive one in the conditions of HHC of Vietnam [6]:

- The concrete height of structure h > 2m
- The minimum dimension of structure a_{min} > 2m

Conditions causing cracks in mass concrete

There are two following parameters that are considered as conditions of causing cracks in mass concrete due to effect of cement hydration process:

- The temperature differential between parts of concrete structure $\Delta T > 20^oC$. This is the necessary condition.
- The Module of temperature differential of concrete structure $M_T \geq 50^oC/m$. This is the sufficient condition.

Without the condition $\Delta T > 20^oC$ cracks will not be occurred in concrete body. But with only one this condition concrete may have or have not cracks.

With both the two conditions cracks must be occurred in concrete body.

M_T is the temperature differential between two points in concrete situated in a distance of 1m.

$$M_T = \Delta T / a$$

Where a is the distance of the two points in concrete body, m.

In critical conditions we have:

$$M_T = 20/a = 50$$
$$a = 20/50 = 0.4m$$

It means that in massive concrete structures only 0.4m around concrete body runs the risk of being cracked. The inside part of concrete is considered as a safety one called a safety core.

By a special software we can make a picture of safety core of mass concrete as showed in Figure 6.

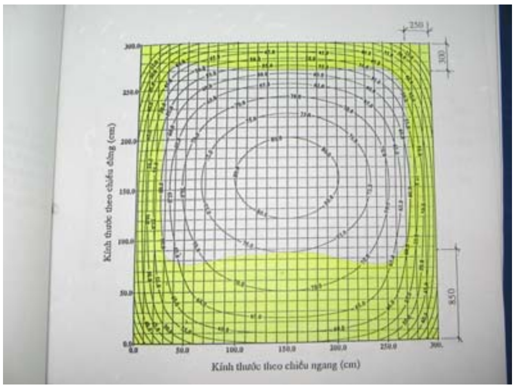


Figure 6 Safety core of mass concrete

Method of preventing cracks

The method of preventing cracks in mass concrete is to do some measures so that the ΔT is allays less than 20°C.

Some measures are as follows:

- Reducing the heat generated by cement, such as:
  - To limit the rate of heat generation of cement in concrete;
  - To use low heat cement;
  - To reduce temperature of fresh concrete (to lower temperature of concrete Materials and water, and to cover fresh concrete from solar radiation)
- Limiting ΔT, such as:
  - To cover concrete body by heat insulation materials;
  - To transfer the heat of mass concrete from interior to surround atmosphere;
  - To devise concrete body into some smaller parts that will not be a mass concrete.

The national standard TCXDVN 305: 2004

The standard [7] was developed by the author consists of following main parts:

- Conditions to be called as a mass concrete structure;
- Conditions causing cracks in concrete body;
- Measures for prevention of cracks in concrete;
- Requirements of design and construction/concreting of massive concrete structures.

Deformation of concrete structures in HHC of Vietnam

Features causing cracks in concrete structures

The figure 7 shows the continue deformation of a concrete roof for one year in the conditions of HHC. The Δ on the figure is the value of deformation restrained by foundation layer which causes tensile stress in concrete structures. If tensile stress is greater than tensile strength of concrete, it cracks.

The results of author's study show the following sutuations:

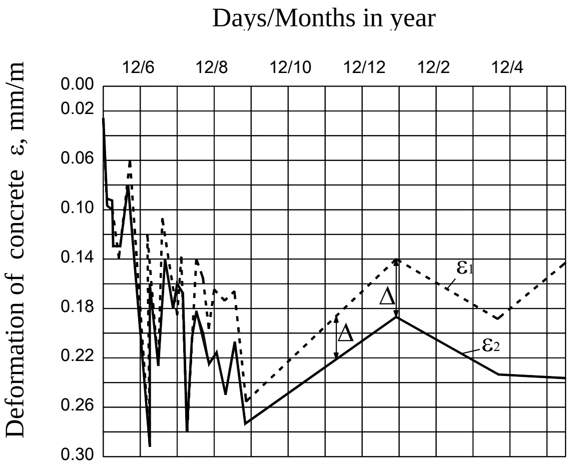
if $\Delta < 0,1$mm/m, concrete does not crack;

if Δ = 0,1÷0,2mm/m, concrete may crack or not depending on properties of concrete and its drying rate;

if Δ > 0,2mm/m, concrete cracks.

In the conditions of HHC of Vietnam cracks due to restrained deformation often appear in rather long structures and in the structures having a composition or curved form restraining their deformation (Figure 8). For prevention cracks, it is necessary to place some so call Hot Humid Deformation Joints- HHDJ.

The results of study of author and colleagues allow to define the spacing and appropriate places of HHDJ in concrete structures.



ε_1- Restrained deformation of concrete roof cemented with foundation layer.

ε_2- Free deformation of concrete roof.

Δ- Value of deformation restrained by foundation layer.

Figure 7 Deformation of concrete roof in HHC conditions

Placing HHDJ for structures

There are two types of HHDJ: Expansion and Contraction Joints. Spacing of these joints are defined as follows:

* *For expansion joints:*

L_{max} = 6m to 9m spacing for open-air structures without reinforcement or having only constructive reinforcement, that are situated under the direct action of hot and humid climatic conditions (such as watertight concrete layer on the roof; road pavements; platforms,..);

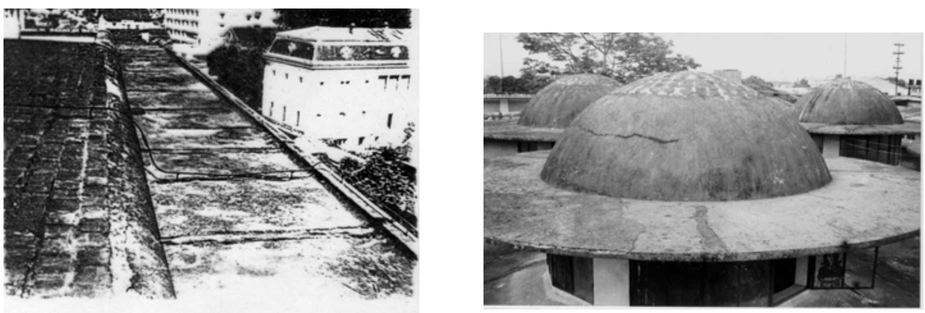


Figure 7 Cracks in concrete structures situated under action of HHC

L_{max} = 9m to 18m spacing for structures having no reinforcement or having only constructive reinforcement that are protected from direct sunlight;

L_{max} = 35m spacing for reinforced concrete structures that are situated under direct sunlight (such as concrete roof; external walls);

L_{max} = 50m spacing for reinforced concrete structures that are protected from direct sunlight (such as concrete roof having heat protective layer; internal walls).

* *For contraction joints:*

lmax = 6m to 9m spacing for any reinforced concrete structures being under the direct action of climatic conditions;

lmax = half of cupola or dome height for structures with form of small cupola or dome being under the direct action of climatic conditions.

Figure 8 shows an example of placing of HHDJ in a concrete road wall in Hanoi with L_{max} = 30m and l_{max} = 9-10m.

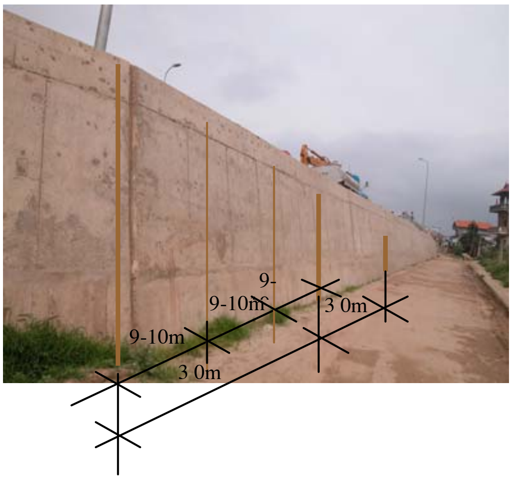


Figure 8 Placing expansion and contraction joints to a concrete road wall in Hanoi

The National standard TCXDVN 313: 2004

The results of author’s study in the field of prevention of cracks in concrete structures working under action of HHC were used for development of the National standard TCXDVN 313:2004 [8] which consists of the following main aspects:

- Prevention of surface cracks of concrete structures;
- Prevention of structural cracks of concrete; and
- Placing of HHDJ in concrete structures.

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