Mass Concrete

Definition

- Concrete in a massive structure, e.g., a beam, columns, pier, lock, or dam where its volume is of such magnitude as to require special means of coping with the generation of heat and subsequent volume change.

Motivation

- Cracks parallel to the axis of the dam endanger its structural stability; a monolithic structure (that is essentially free from cracking) will remain in intimate contact with the foundation and abutments and will behave as predicted by the design stress distributions.

Motivation

- Concrete piers, columns, beams, walls, and foundations for large structures are much smaller than a typical concrete gravity dam. If they are several meters thick and are made of high-strength concrete mixtures (high cement content), the problem of thermal cracking can be as serious as in dams.

Materials and Mix Proportions

- The heat of hydration of a cement is a function of its compound composition and fineness.
- In the event that temperature rise and the subsequent temperature drop of the order of 30 C is judged too high from the standpoint of thermal cracking, one way to lower it would be by reducing the cement content of the concrete provided that this can be done without compromising the minimum strength and workability requirements needed for the job.

Cement content

- By using several methods it is possible to achieve cement contents as low as 100 kg/m3 in mass concrete suitable for the interior structure of gravity dams. With such low cement contents, even ASTM Type II portland cement is considered adequate; substitution of 20 percent pozzolan by volume of portland cement produces a further drop in the adiabatic temperature rise.

Admixtures

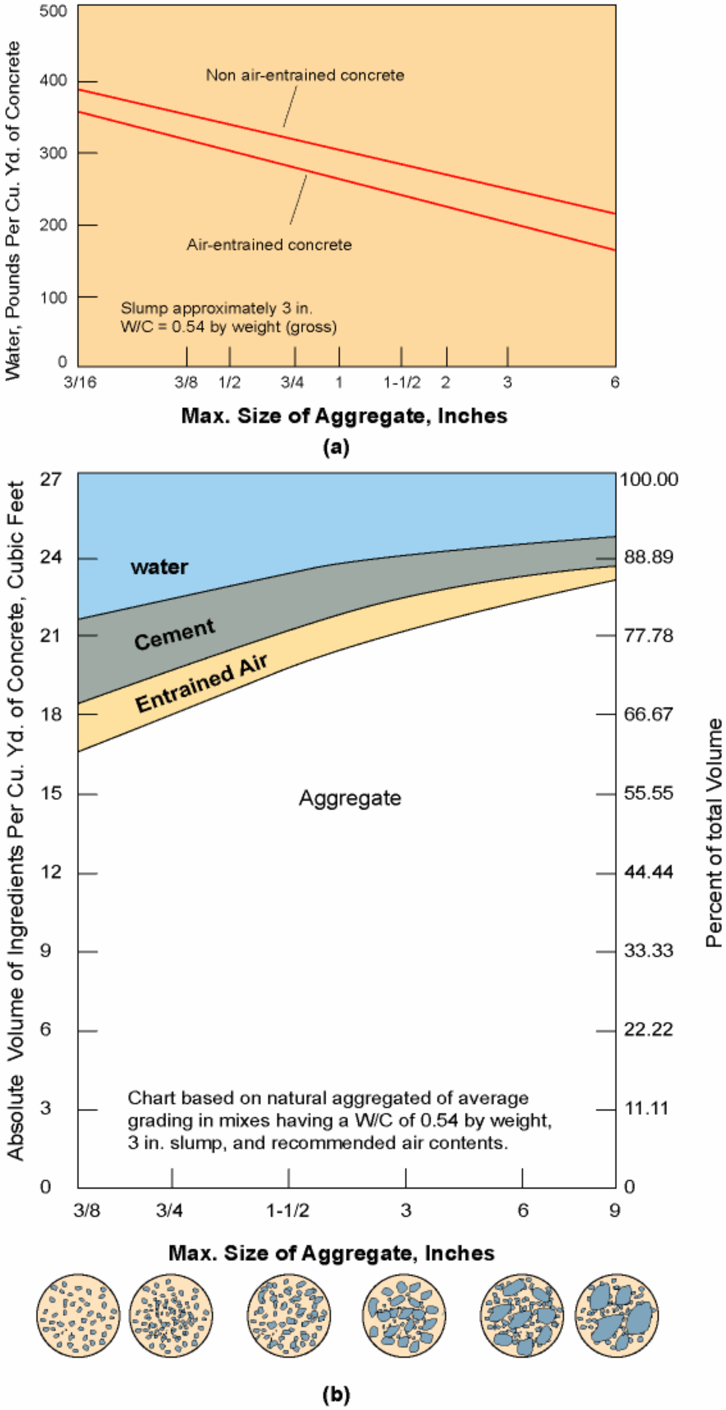
- With cement contents as low as 100 kg/m, it is essential to use a low water content to achieve the designed 1-year compressive strength (in the range 13 to 17 MP) which is normally specified for interior concrete of large gravity structures.
- Approximately 4 to 8 percent entrained air is routinely incorporated into the concrete mixtures for reducing the water content while maintaining the desired workability.
- Increasingly, water-reducing admixtures are simultaneously being employed for the same purpose.
- Pozzolans are used primarily as a partial replacement for portland cement to reduce the heat of hydration, most fly ashes when used as pozzolans have the ability to improve the workability of concrete and reduce the water content by 5 to 8 percent

Aggregate

- With concrete mixtures for dams, every possible method of reducing the water content that would permit a corresponding reduction in the cement content (i.e., maintaining a constant water-cement ratio) has to be explored.
- In this regard, the two cost-effective methods are the choice of the largest possible size of coarse aggregate, and the selection of two or more individual size groups of coarse aggregate that should be combined to produce a gradation approaching maximum density on compaction (minimum void content).

Aggregate

- U.S. Bureau of Reclamation's investigations on mass concrete for Grand Coulee Dam, shows the extent of reduction in water content by the use of entrained air and the largest possible size of aggregate.
- At a given water-cement ratio and consistency, as the maximum aggregate size is increased, both the water and the cement contents are reduced.



Effect of maximum size of aggregate

Aggregate

- Aggregate content and mineralogy have a great influence on properties that are important to mass concrete, such as elastic modulus, coefficient of thermal expansion, diffusivity, and strain capacity.
- The coefficient of thermal expansion of concrete is one of the parameters that determines the tensile stress on cooling. Everything else remaining the same, the choice of aggregate type can decrease the coefficient of thermal expansion by a factor of more than 2.

Strain Capacity

- Some designers feel that designs based on maximum tensile strain rather than stress are simpler for predicting cracking behavior when the forces can be expressed in terms of linear or volumetric changes.

Strain Capacity

- The data show that compared to mortar and concretes, the neat cement paste of the same water cement ratio has a considerably higher tensile strain capacity. In general, the tensile strain capacity increased with the period of hydration and decreased with the size of coarse aggregate.

Strain Capacity

Mix	Aggregate	Maximum size of aggregate [in. (mm)]	W/C + P	Tensile strain capacity 10^{-6} 7 days	28 days
1	Quartzite, natural	3 (75)	0.68	45	71
2	Quartzite, natural	1½ (37.5)	0.68	76	95
3	Quartzite, natural	No. 4 (4.75)	0.68	138	165
4	None (paste)		0.68	310	357
5	Quartzite, natural	1½ (37.5)	0.68	119	139
6	Quartzite, natural	1½ (37.5)	0.40[a]	151	145

Mix Design

- In addition to the largest size of aggregate, determination of the water content should be based on the stiffest possible consistency of fresh concrete that can be adequately mixed, placed, and compacted.
- If the job-site equipment is inadequate for handling concrete with a stiff consistency, alternative equipment should be sought rather than increasing the water and the cement contents of the concrete mixture.

Mix Design

- In the case of precooled concrete, the laboratory trial mixtures should also be made at low temperature because less water will be needed to achieve the given consistency at 5 to C than at normal ambient temperatures (20 to C), due to the slower hydration of cement at low temperatures.

Mix Design

- Determination of the cement content of mass concrete is guided by the relation between water-cement ratio and strength, which is significantly affected by the aggregate texture

Water/cement ratio by weight	Approximate 28-day compressive strength (f'_c), psi (MPa)	
	Natural aggregate	Crushed aggregate
0.40	4500 (31.0)	5000 (34.5)
0.50	3400 (23.4)	3800 (26.2)
0.60	2700 (18.6)	3100 (21.4)
0.70	2100 (14.5)	2500 (17.2)
0.80	1600 (11.0)	1900 (13.1)

Mix Design

- In a moderate or mild climate, generally a maximum of 0.8-water-cement ratio concrete is permitted for interior of dam and lock walls, and 0.6 for exterior surfaces exposed to water.
- The maximum compressive stress in gravity dams that are properly designed against overturning and sliding is fairly low; in MPa units it is usually 0.025 to 0.03 times the height of dam in meters.

Construction practices for controlling temperature rise.

- Post-cooling: The first major use of post-cooling of in-place concrete was in the construction of Hoover Dam in the early 1930s.
- In addition to control of temperature rise, a primary objective of post-cooling was to shrink the columns of concrete composing the dam to a stable volume so that the construction joints could be filled with grout to ensure monolithic action of the dam.
- Due to the low diffusivity of concrete, it would have taken more than 100 years for dissipation of 90 percent of the temperature rise if left to natural processes.

Post-cooling (Hoover Dam)

- The cooling was achieved by circulating cold water through thin-wall steel pipes (typically 25 mm in nominal diameter, 1.5 mm in wall thickness) embedded in the concrete.
- The circulation of cold water was started after the concrete temperature had reached 65 C (i.e., several weeks after the concrete had been placed).
- Subsequently, for the construction of several large dams the U.S. Bureau of Reclamation followed essentially the same practice, except that circulation of cooling water was started simultaneously with the placement of concrete.

Post-cooling

- The first few days following placement the rate of cooling or heat removal can be as high as possible because the elastic modulus of concrete is relatively low.
- The strength and the elastic modulus generally increase rapidly until after the initial peak in concrete temperature has been experienced, which may be some time during the first 15 days following placement.
- When concrete has become elastic, it is important to have the temperature drop as slowly as possible to allow for stress relaxation; under the slow cooling conditions, concrete can stand a 20 C drop in temperature without cracking.

Precooling

- One of the strongest influences on the avoidance of thermal cracking in mass concrete is the control of placing temperature. Generally, the lower the temperature of the concrete when it passes from a plastic state to an elastic state, the less will be the tendency toward cracking.

Precooling

- The first use of precooling of concrete materials to reduce the maximum temperature of mass concrete was by the Corps of Engineers during the construction of Norfork Dam in the early 1940s.
- A part of the mixing water was introduced into the concrete mixture as crushed ice so that the temperature of in-place fresh concrete was limited to about 6 C.
- Subsequently, combinations of crushed ice, cold mixing water, and cooled aggregates were utilized by Corps of Engineers in the construction of several large concrete gravity dams (60 to 150 m high) to achieve placing temperatures as low as 4.5 C.

Pre-cooling

- To raise the temperature by 1 F, water absorbs 1 Btu/lb heat, whereas cement and aggregates absorb only 0.22 Btu/lb.
- It is more efficient to use chilled water in reducing the temperature of concrete.
- The use of ice is most efficient, because ice absorbs 144 Btu/lb heat when it changes to water.
- Cooling the coarse aggregate by spraying with chilled water may be necessary to supplement the use of ice and cooled mixing water.

Surface Insulation

- The purpose of surface insulation is not to restrict the temperature rise, but to regulate the rate of temperature drop so that stress differences due to steep temperature gradients between the concrete surface and the interior are reduced.

Surface Insulation

- After the concrete has hardened and acquired considerable elasticity, decreasing ambient temperatures and rising internal temperature work together to steepen the temperature gradient and the stress differential. Especially in cold climates, it may be desirable to moderate the rate of heat loss from the surfaces by covering with pads of expanded polystyrene or urethane.