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CONSTRUCTION TECHNIQUES FOR CRACK CONTROL OF CAST-IN-PLACE CONCRETE SLABS AND WALLS

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The paper presents recommended construction techniques for crack control of cast-in-place concrete slabs and walls. The crack control in this paper refers to controlling or preventing crack formation during the placing, stiffening and shrinking of fresh concrete. These cracks are influenced by means and methods of construction as opposed to structural cracks due to imposed loads. The techniques affecting construction crack formation involve details regarding volume and length of concrete pour, casting sequence, concrete curing and mix design. These strategies are related directly to concrete joints. Various joint types: saw cut, contraction, expansion and construction joints are discussed. The paper emphasizes that saw cut joint is a dummy or fake joint and has no use for crack control. The suggested techniques recommend the use of full-face construction joints to limit the length of each pour segment to 5m to 10m maximum, followed by water curing of concrete for a minimum elapsed time before placing the adjacent pour. For large projects, several alternate slab panels may be poured simultaneously. The closure pours between the first pour panels can then be cast after the minimum elapsed time. It is noted that continuous wet water curing of concrete is recommended over membrane curing method for better quality control. Lastly, concrete mix which includes 15% to 20% of fly ash is recommended for lower heat of hydration and concrete shrinkage. Several proven examples of successful projects using the recommended techniques, within the past 50 years, are given to confirm the effectiveness of the methods.

Keywords: Crack, Curing, Expansion, Hydration, Joint, Saw cut, Shrinkage.

1 INTRODUCTION

This paper presents proven effective construction techniques for thermal and shrinkage crack control of cast-in-place reinforced concrete slabs and walls. The proposed techniques include considerations of construction joint location, volume of concrete pour, concrete casting sequence, and concrete curing method, as well as concrete mix design. The validity of the suggested techniques is verified by long term observation of actual behavior of real structures. Actual behavior of the real structures is the only exact and accurate solution for any structures.

Unlike steel structural sections which are fabricated in the steel mill with consistent uniform properties, the quality of cast-in-place concrete members such as slabs and walls vary with the means and methods of concrete casting and post-casting operation, detail, and workmanship. These are addressed in the following sections.

2 CONCRETE SLABS AND WALLS, ASSUMPTIONS, AND METHODOLOGY

2.1 Concrete Slabs and Walls

Reinforced concrete slabs and walls are commonly used in civil engineering infrastructure such as rigid pavement, pedestrian sidewalk, concrete bridge deck and parapet wall, concrete floor in buildings, and concrete retaining walls.

2.2 Assumptions

Reinforced concrete slabs and walls discussed in this paper refer to those that are properly designed according to recognized concrete structural design codes such ACI-318 (ACI Committee 318 2019).

2.3 Methodology

This paper is a construction engineering paper (not academia's idealized research paper) and the recommendation's validity is based on the author's own experience using the methods since his first project in 1971. The same method has since been used on concrete projects up to the present time, totaling 50-year span of experience. All projects including water retaining concrete structures which are required to be crack-free and watertight, were built and have performed successfully. The long-term structural response of each structure cited in this paper is its own proof of the methods used.

3 REINFORCED CONCRETE DESIGN OF SLABS AND WALLS

Design of concrete slabs and walls is usually in conformance with concrete structural design code such as ACI-318 (ACI Committee 318 2019). The methods of design are well covered in textbooks such as that by Ferguson *et al.* (1991). The thesis by Seniwongse (1972) gives design methods for reinforced concrete slabs emphasizing upper bound and lower bound approaches and control of concrete crack width of the slabs under service loads. These design documents do not mention construction methods.

4 CONSTRUCTION TECHNIQUES

Design and construction is an art, hence it is not surprising that there have been many different techniques used by different engineers for casting of long slabs and walls. Different details and techniques may lead to vastly different results.

4.1 The Difference is in the Detail

One of the details is concrete joint type and location of the joints. The other detail is concrete pouring sequence and volume of pour. The third detail is concrete curing method. The fourth detail is concrete mix design.

4.2 Joint Types and Joint Location in Slab/Wall Construction

Joint types are given below.

4.2.1 *Saw cut joint - a dummy joint or fake joint*

A saw cut joint called "dummy joint" is not a real joint. The author calls this the "dumb" joint. It is typically a shallow saw cut or groove about 5 mm to 10 mm deep at the surface of concrete slab driveway and sidewalk, and parapet. The saw cuts are spaced regularly at about 2 m. Seniwongse (2019) showed that saw cut joints have no effects on concrete crack control. Figure 1 taken from the paper by Seniwongse (2019) shows concrete cracks within 200 mm parallel to the saw cut lines. Note that the observed cracks never occurred at/along the saw cut lines.

(a) Concrete sidewalk on Park Ave., NYC (b) Bridge parapet wall, Greystone, NY

Figure 1. Concrete cracks despite saw cut lines nearby (pictures taken in 2019).

4.2.2 *Full face joint - a real joint*

Construction joint, contraction joint and expansion joint are full face concrete joints. These are conventional concrete structural joints implementing for the purpose indicating by its names. With experience, engineering intuition and understanding of material and structural behavior, contraction joint can be eliminated and expansion joint can be minimized (Seniwongse 1990).

Construction joint is the surface where two successive placements of concrete meet. The location of construction joints is related to volume of concrete pour for each placement.

4.3 Recommended Concrete Casting Sequence

Volume of concrete pour per segment between construction joints, casting sequence and elapsed time between adjacent pours are important construction details for controlling probable thermal and shrinkage cracks during concrete casting and hydration.

4.3.1 *Maximum volume of pour in a segment*

Limiting the maximum length of continuous pour has been a good old way that experienced engineers have employed to control concrete cracks during construction process. Note that this type of crack is different than concrete crack due to overloading by imposed loads on the structures.

Normally the maximum length of pour is between 5 m to 10 m depending on ambient temperature and humidity during casting, thickness of slab and percentage of reinforcement.

4.3.2 *Minimum elapsed time between adjacent concrete pours*

Minimum elapsed time between the end of the first concrete pour and the adjacent second pour is required to allow the first pour concrete to hydrate, gain adequate strength and bond properly with the embedded reinforcement, without adverse effects of external forces. The external forces due to construction activities of the adjacent pour include foot traffic of construction crews on continuous reinforcing bars, compaction vibration of fresh concrete. Ideally, the first pour concrete should have attained at least 7-day strength before the adjacent pour is placed. This is approximately equal to 72 hours after completion of the first pour. This will also allow the concrete to shrink without external restraints.

4.3.3 *Alternating panel casting for increasing daily total pour volume*

For increasing total pour volume per day, multiple alternate panels (segments) may be poured simultaneously. The closure pours between the alternate segments may then be poured after the minimum elapsed time stated in Section 4.3.2.

Figure 2 shows diagrammatically the alternate segment casting concept for slab-on-grade example.

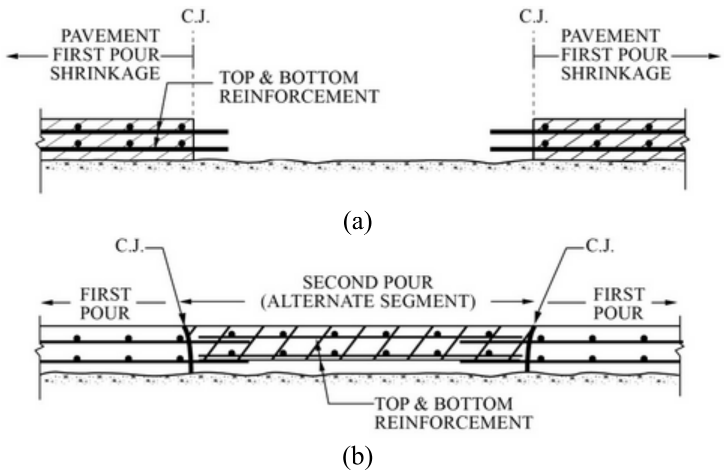

Figure 2. Full face construction joints and alternate panel casting concept (slab-on-grade example).

4.4 Concrete Curing

Concrete curing is important for hydration and maturity of concrete. Two main methods of curing are described by Neville (1995), wet curing and membrane curing. Wet curing uses water, the most basic material known to man. Neville (1995) suggests wet curing over membrane curing for concrete mix with water/cement ratio of 0.50 or lower. From quality control and assurance perspective, the author has always specified wet water curing for all his projects, the reason being every man on site knows water, wet or dry conditions, and there is no fake water, as opposed to fake membrane compounds.

Theoretically concrete control samples (cubes or cylinders) are cured in the laboratory for 28 days. Therefore, field curing should be applied for 28 days also for concrete to reach its maximum potential strength. As a minimum, mandatory 14- day minimum field curing should be enforced.

4.5 Concrete Mix Design- Fly Ash Concrete

Using fly ash concrete instead of Portland cement-only concrete reduces heat of hydration and concrete shrinkage. Fly ash concrete refers to concrete having 15% to 20% of Portland cement substituted by fly ash. Note that fly ash concrete would require prolonged wet curing longer than Portland cement-only concrete.

5 PROVEN REAL-LIFE EXAMPLES

This section presents proven examples from the author's own experience.

5.1 Construction of Surface Reservoirs (1971)

Standard steel surface reservoirs by Sydney Water Board in Australia consist of reinforced concrete mat slab on ground and circular steel plate wall to retain potable water for the city of Sydney. For construction of the circular mat foundation, concrete was cast in alternate sectors. The closure sectors were cast after specified elapsed time. Rubber waterstops were incorporated at the construction joints. The reservoirs have retained water without leakage during all these years of service, proving that the concrete mat was watertight without cracks.

5.2 Construction of Reinforced Concrete Swimming Pools (1995-1998)

Figure 3 shows two swimming pools at the luxurious condominiums in Hua Hin, Thailand. Concrete mat slab foundation and walls of the pools were cast in alternate panels using similar sequence as was done for the water reservoirs described in Section 5.1. The two pools are watertight without cracks and have been in service successfully since 1995 up to the present time.

(a) Chom-View Condominium (b) Lon-Sai Condominium

Figure 3. Watertight swimming pools at Hua Hin, Thailand.

5.3 Construction of Concrete Bridge Deck (1996-2005)

Figure 4(a) and 4(b) show elevated concrete roadways to Terminal Buildings of two International Airports, Don Muang Airport and Suvarnaphoom Airport in Bangkok, Thailand. The deck in Figure 4(a) is continuous reinforced concrete slab, and in Figure 4(b) is concrete slab on concrete girders with continuity slab at the pier.

(a) Viaduct at Don Muang Airport (1998) (b) Viaduct at Suvarnaphoom Airport (2005)

Figure 4. Concrete bridge deck to airport terminal buildings, Bangkok, Thailand.

Figure 5(a) shows the viaduct of the MBTA Green Line Rail Transit in Boston, and Figure 5(b) the North Adams Bridge in Haverhill, in Massachusetts, USA. The superstructures for both bridges are continuous multiple spans of reinforced concrete slab on twin steel box girders.

(a) MBTA Green Line viaduct, Boston (b) North Adams Bridge in Haverhill

Figure 5. Bridges with concrete slab deck in Massachusetts, USA (2005).

During the construction of the concrete slab deck, construction joints were located at the quarter point on both sides of each pier, corresponding to approximate inflection points in the bending moment diagram. Concrete was placed in alternate segments of the deck as described in Section 4.3.3. The constructions were completed successfully. The concrete decks are without cracks.

6 CONCLUSION

This paper has presented recommended construction techniques for crack-free cast-in-place concrete for continuous slabs and walls. The paper dismisses the myth of using saw cut dummy joints. Instead, proper full face construction joints are recommended with limiting maximum length between construction joints. The subsequent adjacent pour should not be made until the first pour concrete has attained adequate bond strength and primary shrinkage has dissipated. Concrete wet curing and fly ash concrete are recommended. The validity of the proposed techniques is supported by the examples of construction projects since 1971 in Sydney, Australia, to projects in Thailand and in the USA, covering the span of 50 years. The same techniques were used, and the same successful results (without cracks in concrete) were consistently achieved.

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