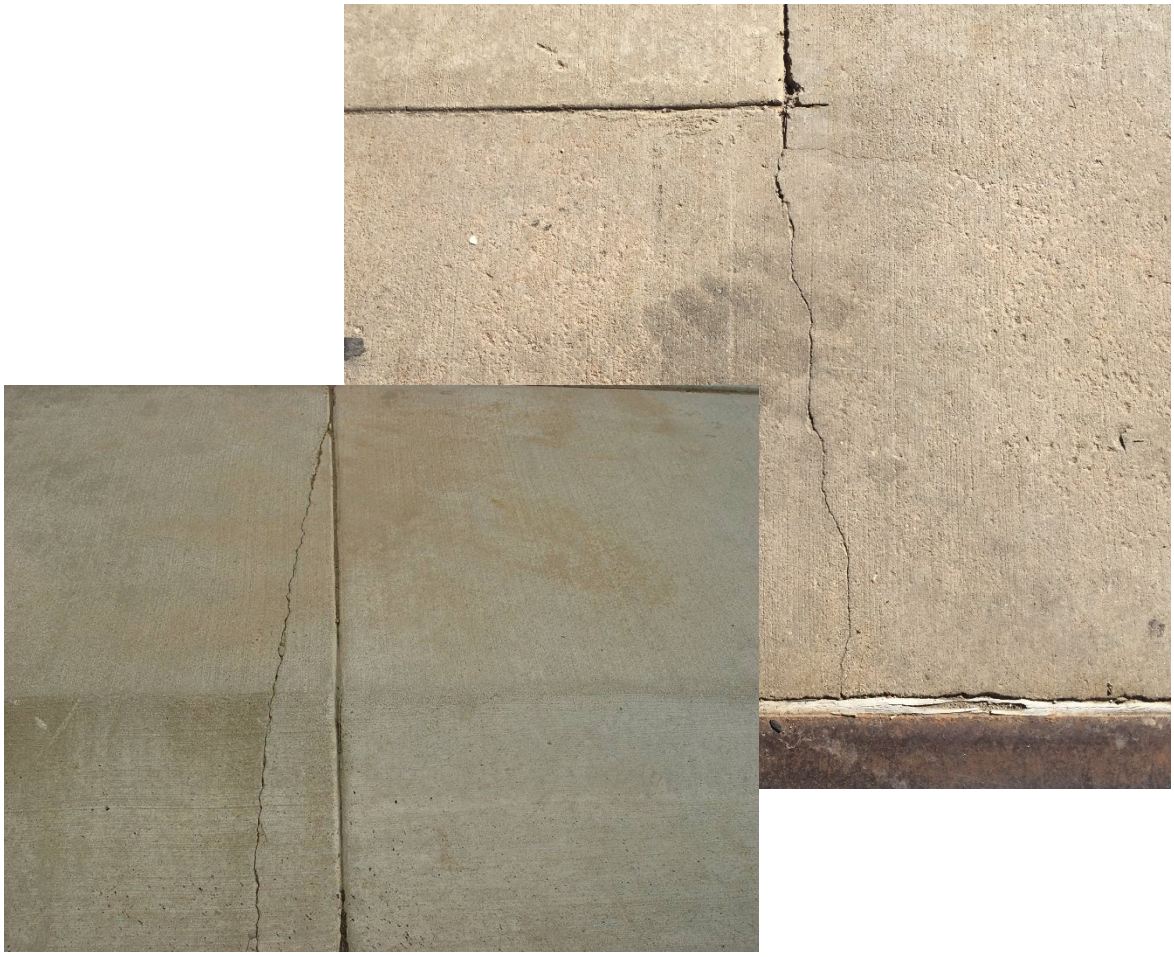
RECLAMATION

Managing Water in the West

Technical Memorandum No. CGSL-8530-2016-13

Joint Spacing for Concrete Structures



U.S. Department of the Interior
Bureau of Reclamation

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Concrete, Geotechnical, and Structural Laboratory Group, 86-68530

Technical Memorandum No. CGSL-8530-2016-13

Joint Spacing for Concrete Structures

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Contents

Table of Figures

Table of Tables

Executive Summary

The Concrete, Geotechnical, and Structural Laboratory group is often asked to assist in locating joints in various concrete structures. There are several different types of joints in concrete structures and their definitions depend on what organization is specifying them. Recommended locations and spacing also varies from organization to organization. This report has collected the various recommendations and developed several tables the Concrete, Geotechnical, and Structural Laboratory group can use when they are called upon to specify joints.

Introduction

Joints in concrete have a variety of purposes. Construction, contraction, expansion, and isolation joints are the primary American Concrete Institute (ACI) and Portland Cement Association (PCA) joints. Construction, control, contraction, and expansion are the primary Reclamation joints. This report has gathered information and documented definitions, recommended joint spacing, and recommended locations from each of the organizations.

Definitions

Referenced in this report are numerous Reclamation, ACI and PCA documents. Some joints do not have the same definition when comparing Reclamation to other industry standards. Listed below are the definitions from Reclamation, ACI, and PCA.

- **Construction Joint**
  - Reclamation
    a. "Construction joints are joints which are purposely placed in concrete to facilitate construction, reduce initial shrinkage stresses and cracks, allow time for installation of embedded metalwork, or allow for subsequent placing of other concrete" and because location of joints is the responsibility of the designer of record, "Locate construction joints where shown on drawings. Relocation, addition, or elimination of construction joints will be subject to approval by the COR." (Reclamation, 2016)
    b. "Construction joints are joints which are purposely placed in structures to facilitate construction or which occur in structures as a result of inadvertent delays in concrete placing operations." (Bureau of Reclamation, 1967)
    c. "Construction joints are the result of practical limitations that interfere with continuous placement of concrete." (Bureau of Reclamation, 1972)

d. "Construction joints are required to the practical limits of placing concrete" (Bernstein et. al, 2009)

e. "A construction joint in concrete is defined as a concrete surface, upon or against which new concrete is to be placed and to which the new concrete is to adhere, that has become so rigid that new concrete cannot be made monolithic by vibration with that previously placed." (Townsend, 1981)

- PCA – "A stopping place in the process of construction. A true construction joint allows for bond between new concrete and existing concrete and permits no movement. In structural applications, their location must be determined by the structural engineer. In slab-on-grade applications, construction joints are often located at contraction (control) joint locations and are constructed to allow movement and perform as contraction joints." (Kosmatka & Wilson, 2016)
- ACI – "Construction joints are placed in a slab to define the extent of the individual placements, generally in conformity with a predetermined joint layout. When concreting is interrupted long enough for the placed concrete to harden, the construction documents should provide a detail to address this unplanned event." (ACI Committee 360, 2010)

- **Control Joint**

  Typically, a Reclamation control joint requires a groove that is ¼ × thickness of the member. However, since Reclamation structures are usually very thick, saw cutting the joint is not practical. Therefore, Reclamation control joints require the contractor to perform a two-part process.

  - Reclamation

    a. "Control joints are joints placed in concrete to provide for control of initial shrinkage stresses and cracks of monolithic units." (Bureau of Reclamation, 2016)

    b. "These (control joints) are planes of weakness along which cracking may take place without marring the appearance of the building." (Bureau of Reclamation, 1972)

    c. "Control joints are unbonded sufaces or planes of weakness built deliberately into the structure along which cracking may take place without marring the appearance of the building." (Bernstein et. al., 2009)

  - ACI – "The familiar term, "control joint," is not included in this list of joint terminology, since it does not have a unique and universal meaning." (ACI Committee 224, 1995)

- PCA – PCA interchanges the definition of a control joint with a contraction joint. See definition of contraction joint.

- **Saw Cut Joint**
  - Reclamation – Saw cut joints are control joints that saw cut the slab within 24 hours following concrete placement. Reinforcement is continuous through the joint. The saw cut creates a weakened plane along which cracking may take place. "Minimum depth of saw cuts shall be ¼ of depth of concrete unless otherwise indicated on the drawings." (Bureau of Reclamation, 2016)
  - ACI – No definition
  - PCA – No definition

- **Partial Contraction Joint**

  The literature search conducted found there are no recommendations listed in any documents reviewed for this study about when to use them, where to locate them, and how often to space them. Therefore, there is no discussion about partial contraction joints in the "Joints by Function" section of this report.
  - Reclamation – "Construct partial contraction joints so no bond exists between concrete surfaces forming the joint. At partial contraction joints, discontinue every other reinforcement bar perpendicular to the joint; i.e. 1/2 of perpendicular reinforcement shall cross the joint." (Bureau of Reclamation, 2016)
  - ACI – "A partial contraction joint has 50 percent or less of the wall reinforcement crossing the joint." "These joints are used primarily in water-retaining structures." (ACI Committee 224, 1995)
  - PCA – No definition

- **Contraction Joint**
  - Reclamation –
    a. "Contraction joints are joints placed in concrete to provide for volumetric shrinkage of a monolithic unit or movement between monolithic units." (Bureau of Reclamation, 2016)
    b. "Contraction joints are joints placed in structures or slabs to provide for volumetric shrinkage of monolithic unit or movement between monolithic units." (Bureau of Reclamation, 1967)
    c. "Contraction joints, which are unbonded sufaces or planes that structurally separate adjacent structures, are used to

relieve tensile stresses induced by shinkage" (Bernstein et.al., 2009)

d. "Contraction joints are provided in a structure to prevent the formation of tensile cracks in the struture as the structure contracts." (Townsend, 1981)

- ACI –

  a. Ch. 3 Buildings – "Planes of weakness to control the location of cracks." (ACI Committee 224, 1995)

  b. Ch. 8 Walls – "The contraction joint is an intentionally created plane of weakness in the wall made by reducing the wall thickness, reinforcement, or both." (ACI Committee 224, 1995)

  c. Ch. 2 Notations and Definitions – "Formed, sawed, or tooled groove in a concrete structure to create a weakened plane and regulate the location of cracking resulting from the dimensional change of different parts of the structure." (ACI Committee 318, 2011)

- PCA- "Weakened plane to control cracking due to volume change in a concrete structure. Joint may be grooved, sawed, or formed. Also known as "control joint"." (Kosmatka & Wilson, 2016)

- **Expansion Joint**
  - Reclamation –

    a. "Expansion joints are separated, unbonded surfaces used to prevent stress or load transfer from one feature or structure to another adjacent feature or structure." (Bureau of Reclamation, 2014)

    b. "Expansion joints , which are unbonded surfaces or planes that structurally separate adjacent structures, eleminate or greatly reduce compressive stresses in concrete that result from thermal expansion, which can crush, buckle, or crack parts of the structure" (Bernstein et.al., 2009).

    c. "Exansion joints are provided in a unit-structure to allow for the expansion of the unit in such a manner as not to change the stresses in, or the position of, an adjacent unit or structure." (Townsend, 1981)

  - ACI –

    a. Ch. 1 Introduction – "Doweled such that movement can be accommodated in one direction, but there is shear transfer in the other directions." (ACI Committee 224, 1995)

b. Ch. 3 Buildings - "limit member forces caused by thermally-induced volume changes. …permit separate segments of a building to expand or contract without adversely affecting structural integrity or serviceability. Expansion joints also isolate building segments and provide relief from cracking because of contraction of the structure." (ACI Committee 224, 1995)

- PCA- "a separation provided between adjoining parts of a structure to allow movement." (Kosmatka & Wilson, 2016)

- **Isolation Joint**
  - Reclamation – No definition
  - ACI –
    a. Ch. 1 Introduction – "An isolation joint isolates the movement between members. That is, there is no steel or dowels crossing the joint." (ACI Committee 224, 1995)
    b. Ch. 5 Slabs on Grade - "the purpose of isolation joints in slabs on grade is to allow horizontal and vertical movement between the slab and adjoining structures such as walls, columns, footings, or specially loaded areas (machinery bases). The movements of these structural elements are likely different than those of a slab-on-grade due to differences in support conditions, loading, and environment." (ACI Committee 224, 1995)
    c. Ch. 8 Walls- "They separate adjacent concrete sections and allow free movement of the adjacent parts. Independent movement of two adjacent walls prevents crushing, warping, distortion, and buckling that could result if they moved together." (ACI Committee 224, 1995)
    d. Ch. 2 Notation and Definition – " A separation between adjoining parts of a concrete structure, usually a vertical plane, at a designed location such as to interfere least with performance of the structure, yet such as to allow relative movement in three directions and avoid formation of cracks elsewhere in the concrete and through which all or part of the bonded reinforcement is interrupted." (ACI Committee 318, 2011)
  - PCA – "separation that allows adjoining parts of a structure to move freely to one another, both horizontally and vertically." (Kosmatka & Wilson, 2016)

Reasons for Joints

Shrinkage

Drying shrinkage is shrinkage of hardened concrete that occurs as the concrete loses moisture. Concrete shrinks and swells based on the relative humidity of its surrounding environment. All concrete will undergo drying shrinkage. As the concrete shrinks from the surface towards its center of mass, tensile stresses are built up in the concrete due to the restraint provided by the inner layers of concrete that are not shrinking as much as the surface. Inner connected parts of concrete, the subbase in slab-on-grade and rebar can contribute to the restraint in concrete that causes drying shrinkage cracking. Contraction joints (ACI and Reclamation), control joints (Reclamation), or saw cut joints (Reclamation) can be used to control the location of cracking due to drying shrinkage. (Kosmatka & Wilson, 2016)

The addition of a shrinkage reducing admixtures can reduce the amount of drying shrinkage in concrete. There are a variety of chemical admixture and concrete additives marketed to reduce drying shrinkage. Minidoka placed the South Headworks slab with a shrinkage reducing admixture (SRA). The placement was approximately 25’ × 100’ × 3’ thick. Recent Reclamation projects have used a chemical and drying shrinkage reducing additives (CDSRA), specifically Prevent-C®, to increase placement size and decrease construction time in mass concrete. This relatively new concrete additive has shown greater benefit than the traditional shrinkage reducing admixtures (SRAs) that were available previously, which only reduce drying shrinkage. Glen Elder used a CDSRA to reduce cracking (not increase placement size). At Echo Dam, the largest placement with a CDSRA was 53’ x 62’ x 5.5’ and currently no cracking has been reported. In the last year additional SRAs (modern SRAs) have been developed by multiple admixture manufactures that claim to be near, or as effective, as Prevent-C®. Research is currently being conducted by the CGSL to compare the performance of modern shrinkage reducing admixtures and to look at a shrinkage-based analysis approach to selecting joint spacing for specific projects. It is anticipated that results of this effort will provide designers with another tool for joint spacing selection in the future.

Thermal Expansion or Contraction

Thermal expansion or contraction can occur due to large temperature changes. The larger the temperature change, the greater the concrete will expand or contract. The potential of concrete to expand or contract depends heavily on mixture proportions and the type of aggregate used (ACI Committee 224, 1995). Although the coefficient of thermal expansion varies depending on the mixture proportions, ACI recommends using the following when determining the expansion or contraction of concrete.

Coefficient of Thermal Expansion = $6 \times 10^{-6}/^{o}F$ (ACI Committee 224, 1995)

Movement

Another purpose for joints in concrete is to allow movement between adjacent structures. Isolation joints (or Reclamation expansion joints) separate concrete structures from one another. When two concrete structures have very different settlement potentials, isolation and expansion joints are used. For example, a concrete slab-on-grade should be isolated from a concrete wall because the wall will not settle as much as the subgrade under the slab. The wall would become a point of restraint for the slab. If one end of the slab settles due to subgrade settlement, a crack would initiate.

Joints by Function

Construction Joints

Reclamation, ACI, and PCA all seem to agree that construction joints are joints designed to support construction operations. However, in some cases, like in the case of slab-on-grade, it is often convenient to locate construction joints to coincide with contraction or isolation joints. In these cases, the joint construction and performance would need to match the contraction or isolation joint requirements.

Performance – Bonding between the first and second placement is required in construction joints. Typically, steel reinforcement will continue through the joint so that shear and flexural continuity is achieved (ACI Committee 224, 1995). In some cases, where large shear loads are transferred, it may be necessary to provide shear keys and or dowels.

Location and Spacing – The type of structures will dictate the location and spacing of construction joints. Listed below are the different structure types and the recommended locations and spacing of the joints.

- Buildings –
    - Reclamation- Joints should be located where "large masses of concrete connect with small masses" or where "high vertical placements join extensive horizontal placements". Joints should also be located at "openings to avoid corner cracks due to settlement" (Bureau of Reclamation, 1972). Reclamation Design Standard for Buildings does not provide a recommended spacing.
    - ACI – ACI stresses the importance of aesthetics. They recommend that when possible, construction joints should "coincide with contraction, isolation, or expansion joints." ACI recommends that the construction joint be located so that it has the "least affect on structural integrity". The designer should locate construction joints so that they can determine the construction joints effect on the structure. ACI recommends that joints in beams and slabs be

located in locations of minimal shear so to ensure the least impact on the structural performance. That is, locate the joints at "points of contra flexure, midspan or middle 1/3 of the span." Vertical joints in walls should be located "near re-entrant corners, beside columns, or other places where they become architectural features." Horizontal joints in columns and walls should be located at the "underside of floor slabs and beams." If a column continues to the floor above, the construction joints should be located "above the concrete slab" (ACI Committee 224, 1995). ACI's recommendation for spacing of horizontal construction joints in walls is "30 feet maximum or the height of a story". The spacing of vertical construction joints in walls shall not exceed 40 feet (ACI Committee 224, 1995).

- Concrete Spillways –
    - Reclamation – Reclamation recommends spacing construction joints in spillways based on "concrete placement capacity, concrete forming requirements, and the need for installation of metal works, etc." due to their large placements (Bureau of Reclamation, 2014). A construction joint spacing was not recommended in Design Guide No. 14.
    - ACI has no recommendations for concrete spillways. However, the recommendations for mass concrete placement or slabs on grade would be appropriate for this case.
- Slab-on-grade –
    - Reclamation – There is no recommendations for construction joints in slab-on-grade in any of the Reclamation design standards.
    - ACI – ACI recommends that construction joints "coincide with isolation or contraction joints." (ACI Committee 224, 1995)
- Concrete Tunnel Lining
    - Reclamation – There is no recommendations for construction joints in concrete tunnel linings in any of the current Reclamation design standards. Joint locations are determined based upon strutural analysis of the tunnel lining system(s).
    - ACI – There are two types of joints in concrete lined tunnels; transverse and longitudinal. Transverse construction joints should be located based on "placing procedures and forming systems". Longitudinal construction joints should be located based on concrete construction sequencing, the cross section, and the parts of the tunnel (ACI Committee 224, 1995). Figure 1 shows the recommended locations of longitudinal construction joints. However, it is important to note that Reclamation does not recommend the joint locations shown in Figure 1. Reclamation

had an experience at Clear Creek Tunnel in California where the joint was located as shown. There was groundwater around the tunnel and no water in the tunnel which caused uplift in the slab and damage due to the location of the joint.

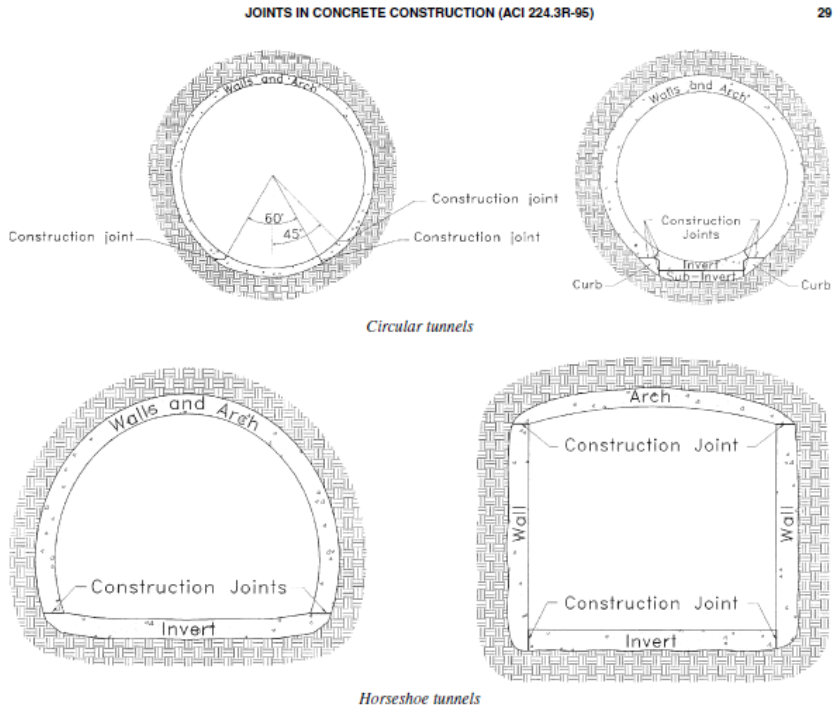


Figure 1. Construction joint locations in concrete tunnel linings. Figure taken from ACI 224.3R-95

- Mass Concrete
    - Reclamation - Construction joints in Reclamation designed concrete dams are typically based on the 5 foot to 7 ½ foot recommended lifts. (Townsend, 1981)
    - ACI- Construction joints in mass concrete placements should be located to "divide structures into convienent working units or permit installation of embedded items" (ACI Committee 224, 1995). The spacing is controlled by "plant mixing capacity, climate during construction, construction schedule, or temperature control requirements." Typically in dams, vertical spacing of horizontal construction joints is "5 to 7 ½ feet for gravity dams and 10 feet or more for thin arch dams, piers, or abutments" (ACI Committee 224, 1995).

Preparation – ACI and Reclamation agree on the preparation of the joint prior to the second placement of concrete. Surface preparation is an important step

because the joint is required to bond to the second placement. The surface of the first placement needs to be clean and laitance free. Surface preparation also requires roughening the surface. Prior to the second placement, the surface is wetted, and then water removed so that the surface is at saturated surface dry conditions. Removal of any standing water is required. Sandblasting or airblasting may be required to achieve the appropriate roughness, but detailed preparation methods is beyond the scope of this report.

Contraction Joints

Reclamation contraction joints are located in structures to account for volumetric changes in the concrete due to shrinkage. ACI and PCA define contraction joints as "planes of weakness to control the location of cracks" (ACI Committee 224, 1995). Many parameters can affect the shrinkage potential of the concrete. Thickness of the slab, the properties of the aggregate, mix proportions of the concrete, the temperature of the concrete and the environmental conditions when concrete is placed will all impact where contraction joints are placed and how often.

Performance – Contraction joints are unbonded between the first and second placement. In contraction joints, shear is transferred perpendicular to the surface through a doweled joint. Typically, reinforcement does not cross the joint. If reinforcement does cross the contraction joint, one end of the slab dowels should be coated with bond breaker to prevent bond of the concrete to the bar, thus preventing restraint of the concrete (Bureau of Reclamation, 1967).

Location and Spacing –

- Buildings
    - Reclamation - There is no recommendations for contraction joints in buildings in any of the Reclamation design standards.
    - ACI and PCA- (Figure 2) represents the recommendations for location and spacing of both PCA and ACI.

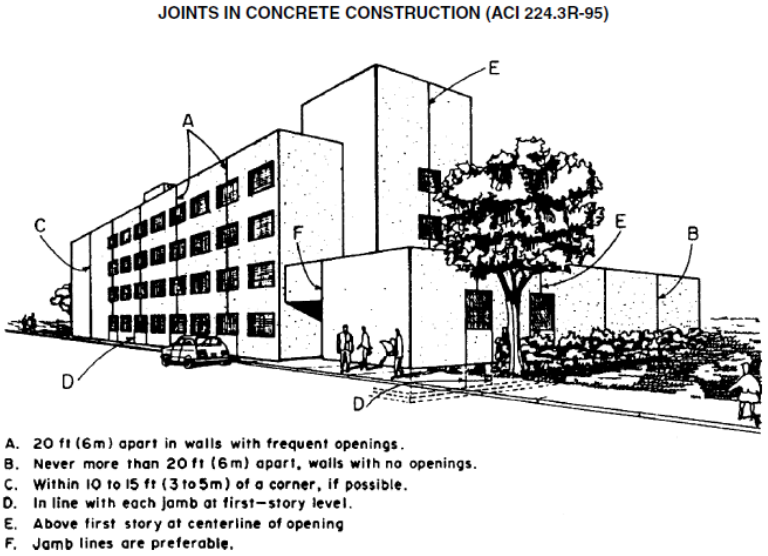


Fig. 3.1—Locations for contraction joints in buildings as recommended by the Portland Cement Association (1982).

Figure 2. Location of contraction joints in buildings. Figure taken from ACI 224.3R-95

- Concrete Spillway
  - Reclamation – Physical features of the spillway, the results of a temperature study, concrete placement methods, and the concrete placement capacity dictate the locations of contraction joints in spillway structures. The recommended spacing ranges from 15 to 40 feet (Bureau of Reclamation, 2014).
- Slab-on-grade
  - Reclamation - There is no recommendations for contraction joints in slabs-on-grade in any of the Reclamation design standards.
  - ACI- The recommended location for contraction joints is at column lines. Ideally, the contraction joints would divide the slabs into squared, but rectangles with a 1:1.25 or 1:1.5 ratio is also ok. The recommended spacing is 24 to 36 times the slab thickness. However, the slump of the concrete can dictate the frequency of joints. The spacing can be greater in low slump concrete than for high slump concrete (ACI Committee 224, 1995). ACI 360R recommends the contraction joints be located on column lines. Depending on the spacing of the columns, additional contraction joints may be required. The additional joints should be spaced equally between columns. The spacing recommended by ACI 360R requires more thought on the part of the designer. The spacing per ACI 360R requires the "mix proportions, quality of the materials, concrete temperature at time of placement, floor slab restraints, base friction, layout of floor discontinuities, and

environmental conditions" to be considered (ACI Committee 360, 2010). Figure 3 shows the recommended locations for contraction joints per ACI recommendations

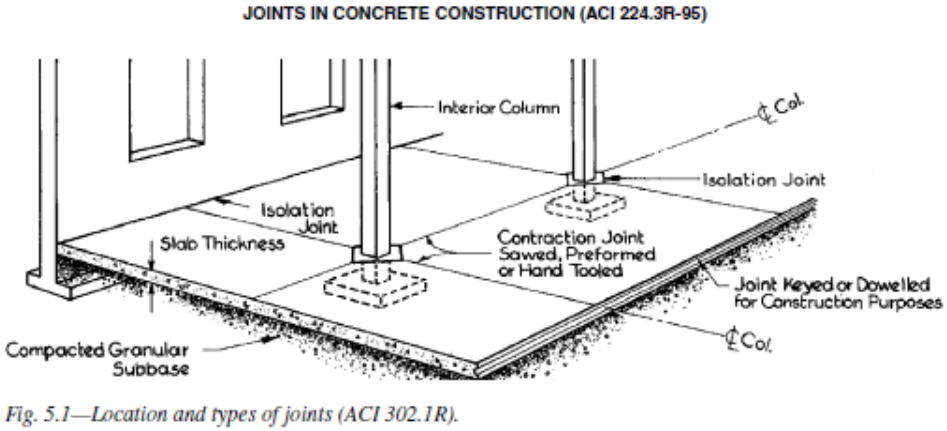


Figure 3. Recommended contraction joint locations. Figure taken from ACI 224.3R-95

- PCA – Similar to the recommendation by ACI, PCA recommends that contraction joint locations be determined based on "slab thickness, subgrade friction, service environment, reinforcement amount, size and location, and the characteristics of the concrete that might make it susceptible to shrinkage." The maximum spacing recommendation is 15 feet (Kosmatka & Wilson, 2016). Figure 7 is the recommended spacing per PCA.

Table 17-4. Spacing of Contraction Joints in Meters (Feet)*

Slab thickness mm (in.)	Maximum-size aggregate less than 19 mm (¾ in.)	Maximum-size aggregate 19 mm (¾ in.) and larger
125 (5)	3.0 (10)	3.75 (13)
150 (6)	3.75 (12)	4.5 (15)
175 (7)	4.25 (14)	5.25 (18)**
200 (8)	5.0 (16)**	6.0 (20)**
225 (9)	5.5 (18)**	6.75 (23)**
250 (10)	6.0 (20)**	7.5 (25)**

* If concrete cools at an early age, shorter spacings may be needed to control random cracking. A temperature difference of only 6°C (10°F) may be critical. For slump less than 100 mm (4 in.), joint spacing can be increased by 20%.

**When spacings exceed 4.5 m (15 ft), load transfer by aggregate interlock decreases markedly. If shrinkage is high or unknown, joints should not exceed 4.5 m (15 ft).

Figure 4. Spacing of contraction joints in slabs-on-grade. Figure taken from PCA Design and Control of Concrete Mixtures.

- Canal Lining
    - Reclamation - Discussions with the Water Conveyance group, provided the following recommendations. Updates to the 1967 Design Guide No. 3 Canals and Related Structures is underway

and the following recommendations have not been published and are subject to change.

- Reinforced concrete linings- Maximum of 25 feet.
- Unreinforced concrete linings, spacing is based on lining thickness
  - Units: Q = cfs; t = inches

UNREINFORCED CONCRETE

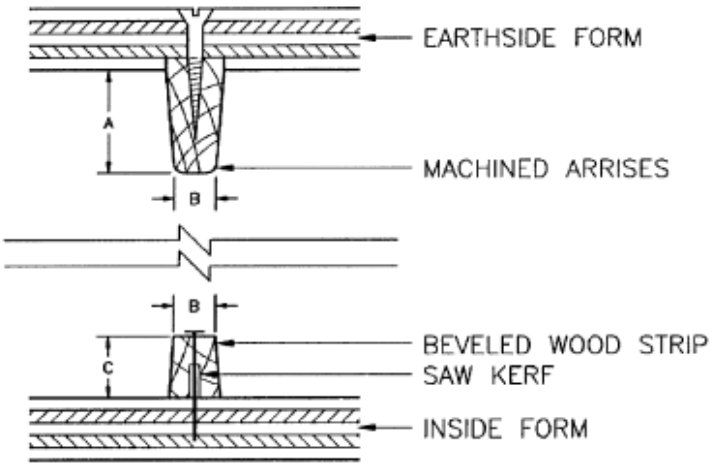
THICKNESS OF CONCRETE LINING	
Q	t
0 to 500	2½
500 to 1500	3
1500 to 3500	3½
3500 to 7500	4
7500 to 20,000	4½

CONTRACTION JOINT SPACING			
Transverse		Longitudinal	
t	C–C	P	C–C
2½	10'	< 20'	None
3	12'	≧ 20'	Maximum spacing same as Transv. C–C
3½	14'		
4	15'		
4½	15'		

Figure 5. Contraction Joint Spacing for Unreinforced concrete linings used by Water Conveyance

  - ACI – ACI recommends concrete canal linings have both transverse and longitudinal contraction joints. The longitudinal joints should be located between the "bottom slab and the side sloped slab". In addition, they recommend placing one "where excavation and embankment fill meet." The recommended transverse spacing for canal linings 4 ½" thick is 12 to 15 feet. Canal linings that are 2" thick should have a maximum spacing of 7½ to 10 feet. Additional longitudinal joints may be required if the canal has a very wide bottom slab. In this case, longitudinal joints spacing should be similar to transverse spacing (ACI Committee 224, 1995).

- Walls
  - Reclamation - There is no recommendations for contraction joints in walls in any of the Reclamation design standards.
  - ACI and PCA – The recommended locations and spacing for walls can be found in the buildings discussion.



	6 in. (150mm)	8 in. (200mm)	10 in. (250mm)
A	1 in. (25mm)	1 1/4 in. (32mm)	1 1/2 in. (40mm)
B	1/2 in. (13mm)	1/2 in. (13mm)	1/2 in. (13mm)
C	3/4 in. (20mm)	3/4 in. (20mm)	3/4 in. (20mm)

Fig. 8.2—Forming contraction joints in walls (PCA 1984).

Figure 6. Recommended contraction joint detail. Figure taken from ACI 224.3R-95

- Mass Concrete
    - Reclamation - Reclamation recommends that "contraction joints are normally spaced about 50 feet apart, but may be controlled by the spacing and location of penstocks and river outlets, or by definite breaks and irregularities of the foundation." "Spacings have varied in dams designed by Bureau of Reclamation from 30 feet to 80 feet as measured along the axis of the dam." "Ratios of 2.0 to 1 or less are desirable, if practicable." (Townsend, 1981)
    - ACI – ACI does not give specific recommendations for spacing, but recommends that the contraction joint locations be determined based on "the results of the temperature analysis, concrete placement methods, plant mixing capacity, and the type of concrete" (ACI Committee 224, 1995).

Preparation –

- Reclamation requires that a contraction joint be prepared by applying a bond breaker to the first concrete placement prior to placing the second placement of concrete. In most cases, the reinforcement in the concrete does not cross the joint. In rare cases where it does, one end of the reinforcement is coated or wrapped with paper. Wrapping or coating the reinforcement will keep the reinforcement from bonding with the concrete and creating a point of restraint.
- ACI and PCA – Figure 7 shows the recommended joint construction details for contraction joints per ACI. Reducing the area of the concrete with notches or saw cuts will control the locations of the cracks. ACI recommends that the surface of the first placement have a bond breaker

applied if a two-part contraction joint is constructed (i.e. no groove in the concrete). The depth of the groove should be ¼ × thickness of the slab or wall (Kosmatka & Wilson, 2016) (ACI Committee 224, 1995). PCA has an additional recommendation of 1" minimum in slabs, but no more than 1/3 the thickness of the slab (Kosmatka & Wilson, 2016).

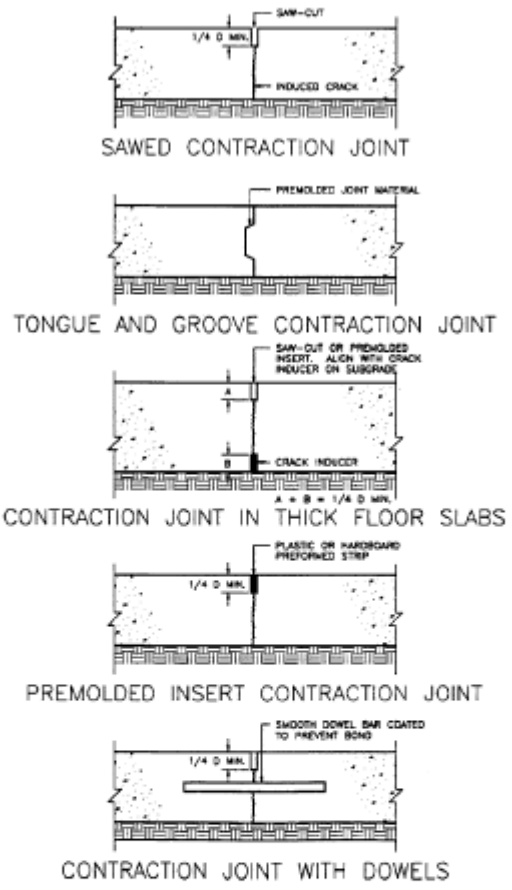


Fig. 5.2—Contraction joint types (ACI 302.1R).

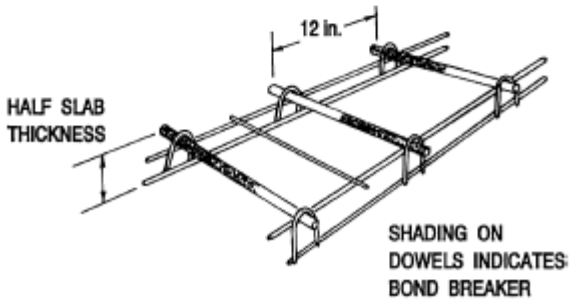


Fig. 5.3—Dowel bar assembly (Gustaferro 1980).

Figure 7. Recommended contraction joint details. Figure taken from ACI 224.3R-95

Control Joints (or Saw Cut Joints)

Reclamation and PCA are the only organizations that recognized the term control joints. PCA uses control joints interchangeably with the term contraction joint. Typically, the construction of Reclamation control joints requires two placements. A two-placement process is required because the concrete placement is too thick to saw cut the slab ¼ × the thickness of the placement. Therefore, Reclamation separates the terminology for "saw cut joints". Saw cut joints create a weakened plane by saw cutting the concrete. Reclamation flatwork placements use saw cut joints.

Performance – Similar to contraction joints per ACI definitions, Reclamation accounts for initial shrinkage of concrete and control the location of cracking with the use of control joints. Therefore, the joint is required to be unbonded. However, reinforcement can continue across the joint.

Location and Spacing – There were only two design guides that discussed the locations of control joints, Design Guide No. 9 Buildings, and Design Guide No. 14 Appurtenant Structures for Dams. The recommended location for buildings were at "regular intervals along the building walls" and "at the center of openings" (Bureau of Reclamation, 1972). There were no recommendations for spacing.

Design Guide No. 14 recommended that control joints be located based on "physical features of the spillway, the results of the temperature study, concrete placement methods, and concrete placing capacity. The recommended maximum spacing is 15 to 40 feet. The same recommended spacing as contraction joints (Bureau of Reclamation, 2014).

Preparation – Reclamation prepares the surface of the first concrete placement with a bond breaker. This recommendation is the same as contraction joint preparation. However, Reclamation recommends that if the control joint is saw cut or tooled, the reinforcement can continue across the joint.

Expansion Joints

Expansion joints separate buildings into segments so that they can expand or contract. This definition of expansion joint is slightly different from the Reclamation definition. Expansion joint locations and spacing are especially important in concrete lined canals. Contractors always want to go as far as possible before installing an expansion joint due to the construction impacts to install the expansion joint. Many will argue that installing expansion joints will increase costs on the project. However, dewatering a canal to fix cracks due to expansion joints that are spaced too far apart may greatly increase the overall cost of the project in the end.

Performance - Expansion joints are structurally separate from the adjacent placement or structure. Reinforcement does not cross the joint and there should not be any bonding of the first placement with the second placement of concrete.

Location and Spacing – Designers locate expansion joints based on the amount of anticipated movement in the system. Expansion joints are often located where two or more walls come together or when a wall changes direction. ACI recommends that expansion joints occur every 200 to 300 feet for very long wall section (ACI Committee 224, 1995). Reclamation recommends that the expansion joint locations in spillways be determined based on the "physical features of the spillway, the temperature study results, the concrete placement methods, and the concrete placing capacity" (Bureau of Reclamation, 2014). Expansion joints in buildings should occur at approximately 150 feet (Bureau of Reclamation, 1972). Discussions with the Water Conveyance group, provided the following recommendations for expansion joints in concrete lined canals. Updates to the 1967 Design Guide No. 3 Canals and Related Structures is underway and the following recommendations have not been published and are subject to change. The maximum recommended spacing based on experience in the Water Conveyance group is 250 feet.

Preparation – Expansion joints should provide separation between adjacent features or structures. Reclamation recommends approximately a 1-inch gap (Bureau of Reclamation, 1972). However, analysis should determine if this gap is enough. Reclamation recommends using a compressible filler such as corkboard, mastic, or sponge rubber to fill the gap. Compressible fillers allow expansion to occur.

Isolation Joints

Reclamation does not recognize the term "isolation joints" in any of the design guides or specifications. ACI and PCA use the term isolation joints when referring to a joint that completely separates one unit from another.

Performance - Similar to Reclamation defined expansion joints, ACI and PCA recommend that isolation joints allow "complete freedom of vertical and horizontal movement" (ACI Committee 360, 2010) (Kosmatka & Wilson, 2016). Reinforcing steel should stop at the joint and there should be no bond between adjacent placements.

Location and Spacing – Per ACI and PCA, isolation joints are typically used in concrete slabs on grade to separate the slab from different structural elements that may create points of restraint or different settlement potential. ACI recommends isolation joints are located at the "junction of slabs and walls, column, equipment foundations, footings, and other points of restraint" (ACI Committee 360, 2010). Figure 8 shows the recommended location of isolation joints per ACI.

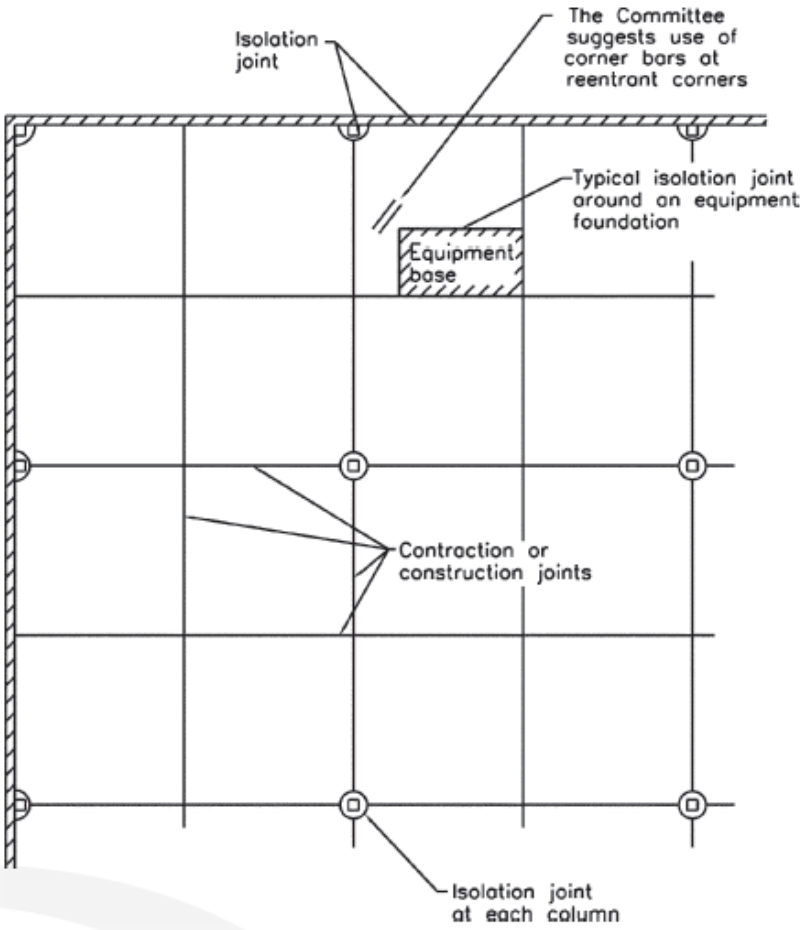


Fig. 5.2.9—Appropriate locations for joints.

Figure 8. Recommended location of isolation joints in slabs. Figure taken from ACI 302.1R-15

Preparation – Isolation joints require full depth break in the concrete. There should be no bond between adjacent concrete units. The filler should be provided full depth and accommodate expansion or contraction. The filler should also allow horizontal and vertical moment. Reinforcement should not continue through the joint.

Summary of Joint Spacing

The following are summaries of the recommended joint spacing for construction, contraction, control, expansion, and isolation joints. The tables separate the recommendations based on organization; Reclamation, ACI, or PCA. Reclamation does not recognize the term isolation joint and ACI does not recognize the term control joint, so "n/a" for "not applicable", was placed in those respective boxes.

Table 1. Summary of Recommended Joint Spacing for Buildings

	Buildings				
	Construction	**Contraction**	**Control**	**Expansion**	**Isolation**
Reclamation	no recommendation	no recommendation	no recommendation	no recommendation	n/a
ACI	● Horizontal Joint 30 feet or Story height ● Vertical Joint 40 feet	● Vertical Joint 15 to 30 feet or 1 to 3 × wall height	n/a	no recommendation	no recommendation
PCA	no recommendation	no recommendation	no recommendation	no recommendation	no recommendation

Table 2. Summary of Recommended Joint Spacing for Slab-on-Grade

	Slab-on-Grade				
	Construction	**Contraction**	**Control**	**Expansion**	**Isolation**
Reclamation	no recommendation	no recommendation	no recommendation	no recommendation	n/a
ACI	no recommendation	24 to 36 × slab thickness	n/a	no recommendation	no recommendation
PCA	no recommendation	varies - see Figure 4	see contraction joints	no recommendation	no recommendation

Table 3. Summary of Recommended Joint Spacing for Concrete Tunnel Lining

	Concrete Tunnel Lining				
	Construction	**Contraction**	**Control**	**Expansion**	**Isolation**
Reclamation	no recommendation	no recommendation	no recommendation	no recommendation	n/a
ACI	• Transverse Joint 20 to 40 feet	no recommendation	n/a	no recommendation	no recommendation
PCA	no recommendation	no recommendation	no recommendation	no recommendation	no recommendation

Table 4. Summary of Recommended Joint Spacing for Concrete Canal Lining

	Concrete Canal Lining				
	Construction	**Contraction**	**Control**	**Expansion**	**Isolation**
Reclamation[1]	no recommendation	● reinforced – 25 ft max ● unreinforced – based on thickness see Figure 5	no recommendation	● 250 ft max	n/a
ACI	no recommendation	● Transverse 2" thick - 7 1/2 to 10 ft. 4 1/2" thick - 12 to 15 ft. ● Longitudinal wide bottom- similar spacing as transverse	n/a	no recommendation	no recommendation
PCA	no recommendation	no recommendation	no recommendation	no recommendation	no recommendation

[1] Recommendation's recommendations came from discussion with Water Conveyance group. Recommendations have not been published in Reclamation Design Guides and are subject to change.

Table 5. Summary of Recommended Joint Spacing for Walls

	Walls				
	Construction	**Contraction**	**Control**	**Expansion**	**Isolation**
Reclamation	no recommendation	no recommendation	no recommendation	no recommendation	n/a
ACI	see Buildings table	● Walls greater than 12 ft, space at height of wall. Walls less than 8 ft, space at 3 × wall height ● no greater than 25 feet ● within 10 to 15 ft. of corner	n/a	straight run of wall 200 to 300 ft	no recommendation
PCA	no recommendation	● 20 feet ● within 10 to 15 ft. of corner	see contraction joint	no recommendation	no recommendation

Table 6. Summary of Recommended Joint Spacing for Mass Concrete

	Mass Concrete				
	Construction	**Contraction**	**Control**	**Expansion**	**Isolation**
Reclamation	● Vertical Spacing Gravity dam- 5 to 7 1/2 ft.	● normally 50 ft apart ● can range from 30 ft to 80 ft ● Ratio of construction block 2 to 1	no recommendation	no recommendation	n/a
ACI	● Vertical Spacing Gravity dam- 5 to 7 1/2 ft. Thin Arch dams, piers, or abutments - 10 ft or more	no recommendation	n/a	no recommendation	no recommendation
PCA	no recommendation	no recommendation	no recommendation	no recommendation	no recommendation

Table 7. Summary of Recommended Joint Spacing for Concrete Spillways

	Concrete Spillways				
	Construction	**Contraction**	**Control**	**Expansion**	**Isolation**
Reclamation	no recommendation	15 to 40 feet	15 to 40 feet	no recommendation	n/a
ACI	no recommendation	no recommendation	n/a	no recommendation	no recommendation
PCA	no recommendation	no recommendation	no recommendation	no recommendation	no recommendation

Summary of Bond and Reinforcing

The tables below summarize what joints require bond, what joints required the reinforcement to continue through the joint and what joints could be doweled to allow movement in one direction but restrain movement in another. If the joints are doweled, one end of the dowel should be coated or wrapped with plastic to prevent bonding to the adjacent placement.

Table 8. Reclamation joint requirements

Reclamation Joints			
	Bond Required	**Reinforcement Continues Through Joint**	**Doweled Joint**
Construction Joint	●	◊	
Control Joint		●	
Saw cut Joint (sim to Control)		●	
Contraction Joint			●
Expansion Joint			
Isolation Joint	n/a	n/a	n/a

◊ Indicates reinforcement may or may not continue through the joint.

Table 9. ACI joint recommendations

ACI Joints			
	Bond Required	**Reinforcement Continues Through Joint**	**Doweled Joint**
Construction Joint	●	◊	
Control Joint	n/a	n/a	n/a
Contraction Joint			●
Expansion Joint			●
Isolation Joint			

◊ Indicates reinforcement may or may not continue through the joint.

Future Recommendations

- Reinstate and or update standard drawings that have been removed but appeared in the 1972 Design Guide No. 9- Buildings
    - 40-D-5250 (Control Joint – Type A), 40-D-5251 (Control Joint – Type B), 40-D-4727 (Locations of construction and contraction joints)
- Expand on the definition of expansion joints in the guide specifications. The requirements on how to build them are in the specifications, but a description about its function is lacking. Similar to the discussion

provided for contraction and construction joints, provided a discussion for expansion joints.

- Update Design Standards to include more rules of thumb or spacing recommendations.
- Form a task group with members from all Civil Engineering Services Division and a member from the Engineering and Laboratory Services Division's Concrete group that would work on having a complete document with Reclamation recommendations and standard details to go with it.

References

ACI Committee 224. (1995). Joints in Concrete Structures (ACI 224.3R-95). Farmington Hills, Michigan: American Concrete Institute.

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Bureau of Reclamation. (1967). Design Standard No. 3 Canals and Related Structures.

Bureau of Reclamation. (1972). Design Guide No. 9 Buildings.

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Kosmatka, S. H., & Wilson, M. L. (2016). Design and Control of Concrete Mixtures. Skokie, Illinois, United States of America: Portland Cement Association.

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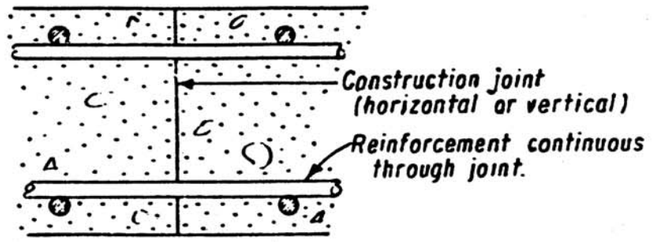
Townsend, C. L. (1981). *Control of Cracking in Mass Concrete Structures.* U.S. Department of the Interior, Bureau of Reclamation, Dams Branch Divison of Design Engineering and Research Center. Washington, D.C.: United States Government Printing Office.

Appendices

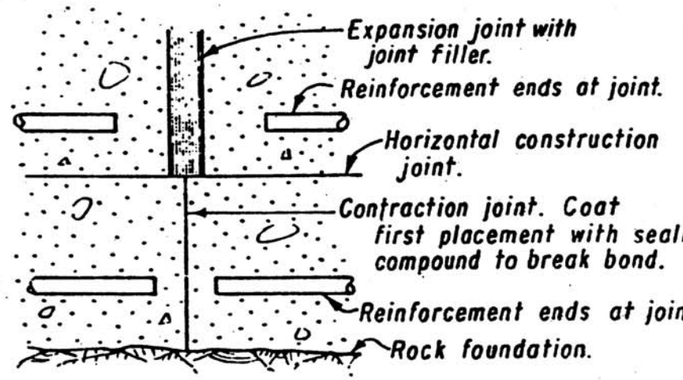
Appendix A: Reclamation Standard Joint Drawings

Appendix A:

Reclamation Standard Joint Drawings



CONSTRUCTION JOINT



EXPANSION AND CONTRACTION JOINTS

NOTE: Construction joint keys and waterstops required if shown on construction dwgs.

FORMERLY 103-D-219

2-11-71 D-N.O.B.	DELETED "CORK" AND REFERENCE TO SEALS

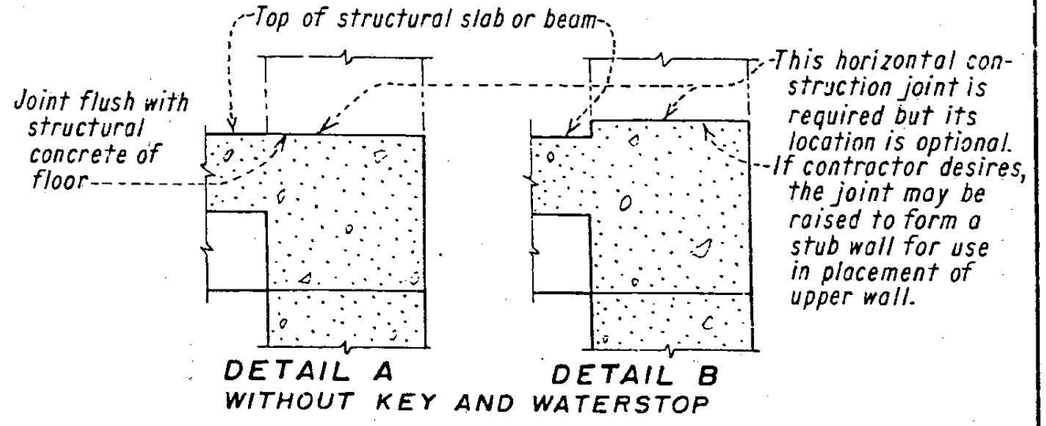
ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
STANDARD DESIGNS
BUILDINGS

JOINTS IN CONCRETE STRUCTURES

DESIGNED H.M.B. SUBMITTED
DRAWN C.A.R. RECOMMENDED
CHECKED APPROVED
CHIEF ENGINEER

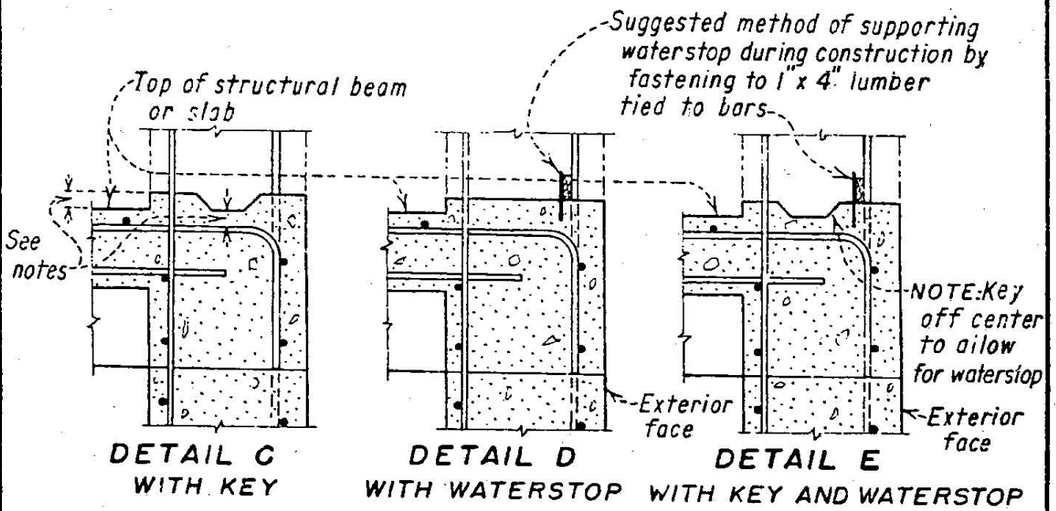
DENVER, COLO., DEC. 4, 1958 — 40-D-5247



STUB WALL OPTIONAL

(Except as otherwise noted on construction dwgs.)

SECTIONAL ELEVATION OF EXTERIOR WALLS SHOWN
SIMILAR FOR INTERIOR WALLS



STUB WALL REQUIRED

SECTIONAL ELEVATION OF EXTERIOR WALLS SHOWN

NOTES: Height of stub wall shall be sufficient for bottom of key or waterstop to clear slab or beam top reinforcement by 1" min. See construction drawings for required waterstops and construction joint keys.

ALWAYS THINK SAFETY

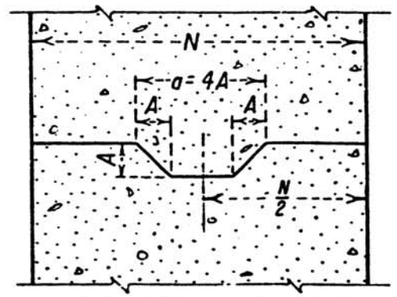
2-11-71 D-N.O.B.	CHANGED "SEAL" TO "WATERSTOP".

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
STANDARD DESIGNS
BUILDINGS

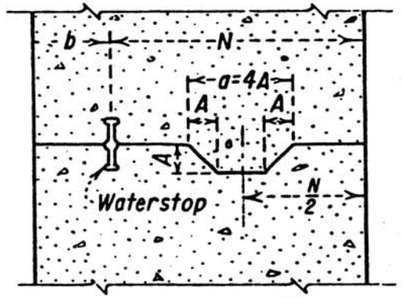
STUB WALL CONSTRUCTION JOINTS

DRAWN M.H.B. SUBMITTED
TRACED V.M.M. RECOMMENDED
CHECKED APPROVED
A-C. CHIEF ENGINEER

DENVER, COLO., DEC. 4, 1952 — 40-D-5248



MEMBERS WITHOUT WATERSTOPS



MEMBERS WITH WATERSTOPS

DIMENSION OF KEYS	
N	A
12" to 17"	1.5"
18" to 22"	2.0"
23" to 27"	2.5"
28" to 32"	3.0"
33" to 37"	3.5"
38" to 42"	4.0"
43" to 47"	4.5"
48" to 52"	5.0"
53" to 57"	5.5"
58" to 62"	6.0"
63" to 67"	6.5"
68" to 72"	7.0"
73" to 77"	7.5"

NOTES

This standard may be used for walls or slabs where shown on the drawings.

Dimension "b" varies with bar cover, bar sizes, and method of support during installation.

One or more keys may be used for members 6'-0" thick or over.

For multiple keys, use key with dimension "A" = 4 inches.

2-11-71 D-H.O.B.	REMOVED RESTRICTION ON WATERSTOP MATERIAL.
10-21-55 D.- I.G.T.	RETRACED AND REDRAWN

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

STANDARD DESIGNS

CONSTRUCTION JOINT KEYS

DRAWN T.R. SUBMITTED Samuel Judd
TRACED L.E.H. RECOMMENDED K.B. Keener
CHECKED H.A.-H.E. APPROVED W.E. Blomgren
Asst. CHIEF ENGINEER

DENVER, COLORADO 12-4-52 | 40-D-5249