

RCC Lift-Joint Strength

Corps of Engineers practices emphasize rigorous design and construction provisions for lift joints in dams, especially when seismic loading is anticipated

BY JOHN R. HESS



Horizontal lift joints in roller-compacted concrete (RCC) structures, like those of conventional mass concrete dams, are planes of weakness subject to leakage, deterioration, and possible failure from tensile or shear stresses. Because lift joints in RCC are generally 1 ft (0.3 m) apart and those in conventional mass concrete dams are often 5 ft (1.5 m) apart, RCC dams may have five times as many lift joints.

With more lift joints in RCC, the risk of lift surface deficiency is somewhat greater than it is in conventional concrete dams. These deficiencies may reduce lift-joint tensile (bond) and shear strength. The reductions sometimes have effects beyond the ordinary aspects of strength, including lower effective modulus at the lift joints, and possibly different dam response to sustained and dynamic forces and possible concentration of stresses.¹ Consequently, the design and construction conditions for RCC dam lift joints must be no less rigorous than for conventional concrete dams, especially when seismic loading is anticipated.

Past evaluations of lift-joint strength

Most studies on RCC lift-joint strength have been associated with RCC dam projects dating from 1988, and much of this work suffers from inadequate or limited numbers of specimens tested. Recovering all the cores from RCC test sections with lift joints is rare because of low lift-joint strength, poor drilling practices, or both. Bedding the joints with a mortar mixture or a highly sanded conventional concrete increases shear capacity, but even for projects with bedded joints, core recovery generally varies from 65 to 85%.

At Willow Creek Dam, for a wide variety of mixtures, lift-joint recovery for "fresh" lift joints averaged about 56%, while bedded lift joints averaged 100% lift-joint recovery.

Based on lift-joint shear strength test results from several conventional concrete and RCC laboratory studies and construction projects, McLean and Pierce concluded that use of an assumed value of shear cohesion (c) equal to 10% of compressive strength ($c = 0.1 f'_c$) was unconservative for RCC mixtures. They suggested that any assumption for $c > 0$ should be supported by test results.²

Dolen and Drahushak-Crow reported on lift-joint testing on Galesville Dam, where 6-in.-diameter (150 mm) cores were drilled with a single tube core barrel. Workers obtained only 24% lift-joint recovery for unbedded lift joints due to partial damage caused by the core drilling process. For bedded lift joints, they attained 76% lift-joint recovery. Limited direct shear strength testing on the lift joints indicated that bedding increased the lift-joint shear strength compared with unbedded lifts.³

Opposite: Lift-joint treatment methods used for roller-compacted concrete include air-blast cleaning, water cleaning, and various applications of bedding mortar (photo credits: USACE and Gannett-Fleming)

Dolen and Drahushak-Crow also reported on three coring programs for lift-joint testing at Upper Stillwater Dam in 1985, 1986, and 1987, which yielded 6-in.-diameter (150 mm) cores using a double tube core barrel. Core recoveries were 60, 80, and 95% in the 1985, 1986, and 1987 programs, respectively. The improvement in 1987 was attributed to drilling the cores at a greater age for the RCC, and to significant adjustments in the RCC mixtures placed in 1986, which resulted in lower Vebe times, increased workability, less segregation, and reduced voids. For the lift-joint cores recovered, the strength was essentially the same as the parent (unjointed) RCC for the high-cementitious mixtures used.³

In tests conducted for a field trial and laboratory study, Dolen and Tayabji conducted direct tensile-strength testing on a limited number of cores, with results indicating that mortar- and concrete-bedded lift joints had a direct tensile strength nearly the same as that for the parent RCC. Lift-joint core recovery indicated significant lift-joint strength improvement with the use of lift bedding for both lean and richer cementitious RCC mixtures.⁴ Gaekel and Schrader reported results from test blocks for Conception Dam that indicated a dramatic increase in lift-joint shear strength due to the use of a bedding mixture that included coarse aggregate.⁵

A limited number of shear-strength tests by Reynolds et al. were made at the RCC Victoria Replacement Dam in Michigan, with some of the samples being extracted from angled drill holes. These tests indicated that the use of bedding mortar on lift joints improved lift-joint shear strength over that of unbedded lifts.⁶

Pacelli et al. discussed treatment of joints in conventional concrete and RCC dams, including results for direct tensile strength from two large-scale test sections for Serra da Mesa RCC cofferdams. They found that mortar bedding improved lift-joint bond strength, that cleaning with low pressure air-water jets had little effect on lift strength, and that a time interval beyond 8 hours between lifts significantly reduced lift strength.⁷

Schrader⁸ reported that results of limited lift-joint shear tests for Miel I indicated that use of lift-joint bedding, retarded RCC mixtures, and increased cementitious contents all increased cohesion and had little effect on friction angle. Extended lift exposure times reduced cohesion and had little effect on friction angle. In another study, lift-joint recovery was 100% for bedded lifts and 62% for unbedded lifts. In these studies on cores drilled from an RCC test section, bedding mortar applied to the lift joint significantly improved lift-joint direct shear strength, particularly cohesion.⁹

Core recovery was 90% when Forbes and Williams reported on 4-in.-diameter (100 mm) lift-joint cores that were removed from the 2-year-old Cadiangullong Dam. The dam was constructed with 2-in. (53 mm) nominal-maximum-size-aggregate RCC. Direct tensile strength of

the lift joints averaged 5% of the compressive strength, and was about 70% of the parent RCC direct tensile strength.¹⁰

Liu and Tatro¹¹ discussed USACE experience with RCC for dams and reported lift-joint strengths for four USACE RCC projects. Green, Neeley, Reed, and Amundson¹² reported additional lift-joint shear strength test results on 6-in.-diameter (150 mm) cores from Elk Creek Dam, where bedded lift joints tested in direct shear produced cohesion nearly equal to that of the parent RCC. These test results generally indicate higher lift-joint shear strength when bedding is used, increased cohesion with bedding, and relatively constant friction angle with or without bedding.

These and past USACE studies support the following conclusions for RCC lift-joint strength:

- Lift bedding generally increases lift-joint strength for RCC, but as the mortar content of the RCC increases, the benefit of the lift bedding decreases;
- Lift bedding may increase cohesion and likely has no effect on friction angle;
- Surface-dry lift surfaces (without overdrying) may increase lift strength;
- Moderate lift cleaning increases lift strength; and
- Relationships between lift-joint strength and compressive strength are generally not reliable (such relationships may be used for preliminary analysis, but testing is necessary to determine lift-joint strength properties for final design).

The last statement forms an essential basis for USACE practice covering RCC lift-joint strength.

Testing practices for lift-joint strength

Splitting tensile test results tend to overpredict actual tensile strengths by as much as 25 to 30%, and should be adjusted by a strength reduction factor of 0.75 to reflect results that would be obtained from direct tensile tests. Direct tension tests are more difficult to conduct than splitting tensile tests, are more affected by drying and microcracking of specimens, and produce more variable test results when compared to splitting tension tests. Because of the problems involved with the direct tension test, the splitting tensile test has historically been more commonly used to evaluate the parent tensile strength of RCC mixtures. The splitting tensile test is difficult to use for evaluating lift-joint strength due to the orientation of the failure plane along the axis of the core. The direct tension test is used to evaluate the tensile strength of the lift joint, the tensile property of most interest for RCC structure design.

Two procedures are generally used for direct shear strength testing: CRD-C 89 and CRD-C 90. Confined shear tests are usually conducted at a minimum of three confining pressures. The upper confining pressure selected for dams should represent at least the maximum height of the structure.

Corps of Engineers practice for selecting lift-joint strength

Prediction of lift-joint strength based solely on compressive strength is generally not reliable. USACE practice for selecting lift-joint tensile strength is based on the use of tables for a preliminary estimate, with a final lift-joint tensile-strength determination based on laboratory tests. USACE practice for selecting lift-joint shear strength is based on guidance for preliminary values, with final values determined by laboratory testing. The design values for lift-joint tensile and shear strength should be based on a laboratory test program that includes evaluation of joint strength using core or sawn block samples from test placements constructed under anticipated field conditions.

Strength properties are strain-rate sensitive, and the strain rates that occur during major earthquakes are on the order of 1000 times greater than those used in standard laboratory testing. Although little testing of RCC for rapid-load (earthquake) strength properties has yet been done, there is no reason to expect results for RCC to be much different from test results for conventionally placed mass concrete. During seismic events, strain rates are related to the fundamental period of vibration of the dam, with the peak stress reached during a quarter cycle of vibration. For a typical gravity dam, this may mean loading the specimens to ensure that failure occurs in about 75 milliseconds, depending on the period of the structure.

Results from laboratory tests on conventional concrete by USBR, USACE, Raphael, and others, indicate approximately a 30% increase in compressive strength and 50% increase in tensile strength of moist specimens under rapid loading conditions. The use of moist specimens for the normal load rate (static) strength tests is critical for this test procedure. The use of dry specimens will generally increase static compressive strength, but will not affect the rapid-load tests. Such test results will then suggest there is no increase in strength from normal to rapid-load rates.

Some RCC mixtures, depending on the shape and gradation of the aggregates, and the degree of compaction and segregation present in the RCC, may exhibit stronger anisotropic properties than conventional mass concrete. Strength tests on several RCC projects indicate that, in some cases, cores drilled vertically yield higher strengths than companion cores drilled horizontally (also observed in conventional concrete).^{9, 13} For conventional concrete, the anisotropic behavior is usually attributed to accumulation of bleed water under aggregate particles. For RCC, the observed anisotropic behavior may be due to the distribution and orientation of aggregate particles resulting from spreading and compacting of the horizontal RCC layers. The orientation of cores can influence tensile strength results by as much as 20%. If tensile strength is

of structural importance, drilled cores of both vertical and horizontal orientation should be tested. In at least one international RCC dam project, the anisotropic nature of the RCC strength properties was accounted for in adjustment factors for design strength.¹⁴

Tensile strength

Cannon¹³ and Raphael¹⁵ discuss the tensile and compressive strength of concrete for dams; the test methods used for measurement; the differences in test measurements; the effects of rapid-load testing; and the resulting trends in strength results. The ratios of tensile strength to compressive strength for RCC mixtures have typically ranged from about 5 to 15%, depending on aggregate quality, strength, age, and test method. Cannon and others have compared these ratios and found them to vary widely.¹⁶

Cannon found that the ratio of tensile to compressive strength decreased as strength level increased. The USACE uses Tables 2 and 3 for development of preliminary lift-joint tensile strength properties, based on selection of a preliminary compressive strength and RCC mixture characteristics.¹⁷ Core tensile strength will generally be lower than equivalent cylinder tensile strength.

Tables 2 and 3 present a means for determining preliminary lift-joint direct tensile strengths for design from splitting tension tests conducted on the parent RCC. The factors used in Tables 2 and 3 are based on historical data.¹⁷ When test data aren't available, these tables provide a range of preliminary design values for RCC mixtures based on mixture workability, aggregate size and type, and lift-joint preparation. Low values of lift-joint direct tensile strength are based on natural aggregates, low-strength aggregates, and unbedded lift joints. High

Table 1:
RCC core shear and direct tensile strength test results (USACE)

Dam	Lift treatment	No. of tests	c (peak) psi (MPa)	φ deg	c/f'c	c/cp	Lift-joint recovery (%)	fdi psi (MPa)
Zintel Canyon, Wash. ¹¹ Vebe = 14 sec C+P = 125+0 lb/cy (74+0 kg/m ³) MSA = 2.5 in. (64 mm)	parent	6	290 (2.00)	56	.19	-	-	-
	no bedding	9	85 (0.59)	56	.06	.29	38	-
	bedding	9	200 (1.38)	54	.13	.69	73	-
Cuchillo Negro, N.M. ¹¹ Vebe = 16 sec C+P = 130+100 lb/cy (77+59 kg/m ³) MSA = 3 in. (76 mm)	parent	16	364 (2.51)	50	.14	-	-	-
	no bedding	7	123 (0.85)	63	.05	.34	20	-
	bedding	17	252 (1.74)	57	.10	.69	64	-
Cache Creek, Calif. Vebe = 17 sec C+P = 298+0 lb/cy (177+0 kg/m ³) MSA = 1.5 in. (38 mm)	parent	9	787 (5.43)	44	.23	-	-	291 (2.01)
	no bedding	6	329 (2.27)	48	.10	.42	36	305 (2.10)
	bedding	5	252 (1.73)	43	.07	.32	33	-
Elk Creek, Ore. ¹¹ Vebe = 17 sec C+P = 118+56 lb/cy (70+33 kg/m ³) MSA = 3 in. (76 mm)	parent	8	449 (3.10)	63	.15	-	-	-
	bedding	8	412 (2.84)	65	.13	.92	-	-

(c = cohesion; cp = cohesion of parent RCC; φ = friction angle; f'c = compressive strength, from cores; fdi = direct tensile strength)

values of lift-joint direct tensile strength are based on all crushed, high-strength aggregates and bedded lifts.

Shear strength

Shear strength is generally represented by a Mohr envelope relationship, as follows:

$S = c + \sigma \tan \phi$ where S = shear strength (MPa), c = cohesion (MPa), σ = normal or confining stress (MPa), ϕ = friction angle (degrees).

Because the shear strength along lift surfaces is always less than that of the parent concrete, shear strength at lift surfaces will govern the design. Shear strength of the parent or lift-joint RCC can be developed from cylinders cast in the laboratory, from blocks of RCC

sawn from test sections, or from cores drilled from test sections or the RCC structure. For preliminary design, values of parent shear strength can be developed from historical data or tests, then modified to represent lift-joint shear strength. Final design shear strength parameters for important structures, such as moderate to high dams, or dams in high-seismic zones, should be developed from laboratory testing of cores or blocks from test sections.

Cohesion in the parent RCC varies with the mixture proportions—especially the amount of paste and water-cementitious material ratio—and with age. The parent RCC friction angle depends primarily on aggregate type and shape, and is relatively independent of factors affecting cohesion.

Generally, the friction angle doesn't change significantly with mixture proportions or age. Values of cohesion for parent RCC have ranged from as little as 75 psi (0.5 MPa) and less to over 600 psi (4.1 MPa).² Workable (Vebe < 30 sec) parent RCC mixtures have cohesion ranging up to 20% of the compressive strength. Less-workable mixtures (Vebe > 30 sec) may have cohesion values less than 10% of the parent compressive strength. RCC friction angles have varied from 40 to 60 degrees.

RCC lift-joint shear strength can be lower than for conventional mass concrete, and may be more variable on some projects. Cohesion varies a great deal from lift surface to lift surface, while the shear

friction angle is usually similar to that of the parent RCC. The ratio of cohesion to compressive strength (c/f'_c) has varied from 0.03 to 0.06 and 0.09 to 0.15 for unbedded and bedded lift joints, respectively. Friction angle for bedded and unbedded lift joints has been essentially unchanged.

Table 2:
RCC, workable consistency M30 sec Vebe vibration (USACE 1995)

Agg size, in. (mm)	Use bedding mortar? Y or N	Max /Min	Split tensile strength of parent RCC (cylinders)		Factor ^a	Design lift-joint tensile strength	
			≤3500 psi (24.1 MPa)	> 3500 psi (24.1 MPa)		≤3500 psi (24.1 MPa)	> 3500 psi (24.1 MPa)
≤3 (75)	-	Max	0.17 f'_c	8.5 (f'_c) ^{1/2} [0.71 (f'_c) ^{1/2}]	0.53	0.090 f'_c	4.5 (f'_c) ^{1/2} [0.37 (f'_c) ^{1/2}]
		Min	0.08 f'_c	5.5 (f'_c) ^{1/2} [0.46 (f'_c) ^{1/2}]	0.53	0.040 f'_c	2.9 (f'_c) ^{1/2} [0.24 (f'_c) ^{1/2}]
>3 (75)	Y	Max	0.17 f'_c	8.5 (f'_c) ^{1/2} [0.71 (f'_c) ^{1/2}]	0.47	0.080 f'_c	4.0 (f'_c) ^{1/2} [0.33 (f'_c) ^{1/2}]
		Min	0.08 f'_c	5.5 (f'_c) ^{1/2} [0.46 (f'_c) ^{1/2}]	0.47	0.040 f'_c	2.6 (f'_c) ^{1/2} [0.22 (f'_c) ^{1/2}]

^a Includes factors for conversion to direct tensile of 0.75, for joint strength and probable percent of bonded joint of 0.70, and 0.90 for NMSA > 3 in. (75 mm).

Table 3:
RCC, less workable consistency >30 sec Vebe vibration (USACE 1995)

Agg. size, in. (mm)	Use bedding mortar? Y or N	Max /Min	Split tensile strength of parent RCC (cylinders)		Factor ^a	Design lift-joint tensile strength	
			≤ 3500 psi (24.1 MPa)	> 3500 psi (24.1 MPa)		≤ 3500 psi (24.1 MPa)	> 3500 psi (24.1 MPa)
≤3 (75)	Y	Max	0.17 f'_c	8.5 (f'_c) ^{1/2} [0.71 (f'_c) ^{1/2}]	0.35	0.060 f'_c	3.0 (f'_c) ^{1/2} [0.25 (f'_c) ^{1/2}]
		Min	0.08 f'_c	5.5 (f'_c) ^{1/2} [0.46 (f'_c) ^{1/2}]	0.35	0.030 f'_c	1.9 (f'_c) ^{1/2} [0.16 (f'_c) ^{1/2}]
>3 (75)	Y	Max	0.17 f'_c	8.5 (f'_c) ^{1/2} [0.71 (f'_c) ^{1/2}]	0.32	0.055 f'_c	2.7 (f'_c) ^{1/2} [0.22 (f'_c) ^{1/2}]
		Min	0.08 f'_c	5.5 (f'_c) ^{1/2} [0.46 (f'_c) ^{1/2}]	0.32	0.025 f'_c	1.7 (f'_c) ^{1/2} [0.14 (f'_c) ^{1/2}]
≤3 (75)	N	Max	0.17 f'_c	8.5 (f'_c) ^{1/2} [0.71 (f'_c) ^{1/2}]	0.18	0.030 f'_c	1.5 (f'_c) ^{1/2} [0.12 (f'_c) ^{1/2}]
		Min	0.08 f'_c	5.5 (f'_c) ^{1/2} [0.46 (f'_c) ^{1/2}]	0.18	0.015 f'_c	1.0 (f'_c) ^{1/2} [0.08 (f'_c) ^{1/2}]
>3 (75)	N	Max	0.17 f'_c	8.5 (f'_c) ^{1/2} [0.71 (f'_c) ^{1/2}]	0.16	0.025 f'_c	1.4 (f'_c) ^{1/2} [0.12 (f'_c) ^{1/2}]
		Min	0.08 f'_c	5.5 (f'_c) ^{1/2} [0.46 (f'_c) ^{1/2}]	0.16	0.015 f'_c	0.9 (f'_c) ^{1/2} [0.08 (f'_c) ^{1/2}]

^a Includes factors for conversion to direct tensile of 0.75, for joint strength and probable percent of bonded joint of 0.70, of 0.90 for NMSA > 3 in. (75 mm) and for bedding mortar (0.67 if bedding mortar is used, 0.33 if not used)

For USACE projects, a preliminary design value of $c/f'_c = 0.05$ is recommended for lift-joint surfaces that are to receive a mortar bedding; otherwise, a value of 0 is assumed. A value of $\phi = 45$ degrees can be assumed for preliminary design or for small projects, for both parent and lift-joint shear strength. Final values of lift-joint shear strength are based on test programs.

Shear strength under rapid loading may or may not behave like rapid-load tensile strength. Until testing of RCC shear specimens under dynamic loading conditions has been accomplished, USACE designers use values of shear strength for tests conducted at the normal load rate.

Corps of Engineers practice for lift-joint design

The design and constructed quality of lift surfaces is critical to the stability and seepage performance of a structure. Mixture proportioning and subsequent testing programs are the first steps in assuring that required performance is attained. Proper specification of construction procedures and field control of construction operations are just as vital to assuring that required performance is consistently attained.

Corps of Engineers practice for lift-joint design and construction is contained primarily in four documents: EM 1110-2-2006, "Roller-Compacted Concrete"; EM 1110-2-2200, "Gravity Dam Design"; EP 1110-2-12, "Seismic Design Provisions for Roller-Compacted Concrete Dams"; and ETL 1110-2-343, "Structural Design Using the Roller-Compacted Concrete (RCC) Construction Process." These and other Corps of Engineers criteria are on the Internet at: www.usace.army.mil/inet/usace-docs/. The USACE design team jointly develops project features, including lift joints, by balancing the design and cost of each feature and weighing the performance of available materials and practices to develop specifications containing practical construction requirements. A key element in selecting RCC project features such as lift-joint design is keeping them as simple as possible. Design values should be selected and conditions controlled so that the design values are reasonably attainable and always attained.

The principles of design specified in EM 1110-2-2200, "Gravity Dam Design," apply to roller-compacted concrete gravity dams. However, there are differences in the requirements for uplift within the body of a RCC dam and additional testing requirements to assure adequate factors of safety against sliding.

Testing of various bedding materials has shown that the use of bedding concrete incorporating coarse aggregate provides slightly better shear performance on lift joints than on similar joints bonded using a bedding mortar with no coarse aggregate. However, bedding mortar is less labor-intensive to apply, and should be the preferred material if large areas are to receive bedding.

The use of a bedding mortar or bedding concrete over the upstream zone of each lift joint is mandatory for Corps of Engineers projects for any dam that will impound water for extended periods. It may be necessary to apply bedding mortar over the full lift surface for dams where appreciable bond strength between lifts is necessary (such as those built in earthquake zones). A designer may consider eliminating the full-area bedding mortar on lift joints for dams with no permanent reservoir, and where structural analysis doesn't require the added joint strength. Future possible uses of the structure (that is, the future conversion of a dry dam to a water storage project) should be considered before eliminating features that are irreversible.

Corps of Engineers practice for lift-joint construction

RCC quality improves, and cost decreases, when the material can be placed as quickly as practical. Slow or interrupted placements may reduce RCC density and produce poor-quality lift surfaces. Following completion of rolling, lift surfaces are generally moistened and kept damp for a period of time before the next lift is placed. Shear testing of lift joints subjected to various moisture treatments indicates that some drying of the lift surface improves bonding at the surface. Allowing an exposed surface to dry to a moisture content just below saturated-surface dry is beneficial. Further drying, however, will decrease the bonding at the surface. Conversely, extra-wet surfaces exhibit lower joint strengths than slightly dry surfaces.

Avoid the use of water trucks or fire hoses with coarse sprays whenever possible. Water trucks often make tight turns and repeated passes that damage the lift surface, and can produce a surface scum because of overwetting, erosion, and tire action. Pipe systems and hand-operated hoses, both with fogging nozzles, can be used to avoid this surface damage. Rapid placement of RCC helps to minimize problems by covering exposed lift surfaces quickly enough to eliminate the need for application of moisture for curing.

Preparations before placement of the overlying lift of RCC should include the removal of all loose material, laitance, debris, standing or running water, snow, ice, oil, and grease from the lift surface. When the underlying RCC is less than 24 hours old, and under ideal conditions, cleanup is best accomplished by simply blowing the surface of the lift with an air nozzle.

Surfaces that are several days old or have excessive damage, debris, or contamination may require more aggressive treatment, using high-pressure air-water blasting. High-pressure water-jet cleaning is generally required only in extreme cases. A vacuum truck is a necessary piece of equipment for conditions where waste material and water can't be easily removed from the surface.

Place bedding mortar in sufficient thickness to fill any voids at the lift surface, but not so thick that lift-joint strength is reduced. A typical bedding mortar contains No. 4 (4.75 mm) sieve maximum aggregate size, is highly retarded, has a slump of 7 to 9 in. (180 to 230 mm), and contains a high quantity of cementitious materials. Place the bedding mortar in a zone about 30 to 60 ft (10 to 20 m) wide in front of the RCC being spread, generally preceding RCC placement by 10 to 15 min. During hot weather, shorten the interval between spreading of the bedding mortar and placement of RCC. Extend the interval during cool weather.

Bedding mortar is usually delivered to the placement area by transit mixer for projects where vehicle access to the lift surface is convenient. The bedding mortar is spread over large areas with small tractors with front-mounted rubber squeegees, or manually spread over small areas with serrated rakes. Bedding mortar has also been applied as wet-mix shotcrete, which allows close control over the thickness of the bedding layer.

Concrete has also been used as a bedding mixture spread to a thickness of 1 to 2 in. (25 to 50 mm) to provide watertightness at the upstream face of some dams. Bedding concrete is usually proportioned with up to 3/4-in. (19 mm) nominal-maximum-size aggregate to have a slump of 5 to 7 in. (130 to 180 mm).

At Elk Creek Dam, workers spread four equal-thickness layers of relatively workable (low Vebe time) RCC to form a 24-in.-thick (600 mm) lift. This was intended to reduce the number of lift joints, increase their shear strength, and decrease seepage through them. Each layer was completely tracked with the spreading dozer for compaction. After placement of the fourth layer, the entire surface was compacted with a vibratory roller, and later received a bedding mortar just prior to placement of the next four layers of RCC. This method minimizes the number of lift joints and strengthens the full joint by the use of bedding mortar over the entire lift surface.

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