ROLLER COMPACTED CONCRETE

(RCC)

INNOVATIONS
In CIVIL CONCTRUCTIONS WORLD

By

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Contains

RCC- Roller Compacted Concrete

Introduction

During my experience in civil engineering constructions also during my views of the situation of our constructed roads in Iraq generally and Kurdistan reign especially which the heavy trucks ways in the roads always are damaged because of bad design, bad executions of the road projects or the overload of the heavy trucks and equipments which always breaking the laws of road load limits.

Therefore extra costs are added to all Road constructions by constructing reinforced concrete roads in trucks ways and highways or all the roads to prevent the damages to the road which costing our contry large quantities of concrete materials and steel reinforcement and more and more extra durations for executing.

So that I made some searches in the internet for solutions to this case and I found something like a magic it is an invention and new development which I think it will solve all our problems in our high ways and roads and that was the Roller Compacted Concrete.

Roller-compacted concrete, or RCC, takes its name from the construction method used to build it. It's placed with conventional or high-density asphalt paving equipment, and then compacted with rollers.
RCC has the same basic ingredient as conventional concrete: cement, water, and aggregates, such as gravel or crushed stone.
But unlike conventional concrete, it's a drier mix—stiff enough to be compacted by vibratory rollers. Typically, RCC is constructed without joints. It needs neither forms nor finishing, nor does it contain dowels or steel reinforcing.
These characteristics make RCC simple, fast, and economical.

RCC or Roller compacted concrete was limited to the sub-base of roads and airfield pavements and concrete dams, being called lean concrete or dry lean concrete. RCC became popular due to the fact that it is a simple material to produce and place. RCC (Rolled Compacted Concrete) has low cement content, about 110 to 120 kg/m3, and uses washed aggregate of concreting quality. American Concrete Institute (ACI) 207.5R-89 defines roller compacted concrete (RCC) as concrete compacted by roller compaction. RCC got its start in the Seventies During all the worlds especially in United State of Amerce and Canada.

The first Roller Compacted Concrete (RCC) dam of the world was Alpe Gera at Sondrio in North Italy. It was executed from 1961 to 1964. The technology in that period is not what it is today. This dam had a total quantity of concrete of 1,800,000 cubic meters of concrete. Concrete feeding to the dumpers moving on dam was done by use of 6 cubic meters skips moving on an inclined haulage track. This method of construction was found to be expedient then.

With the advent of opening the economy, speedy and economic construction of dams for hydro power and/ or irrigation has become necessity of the day. Though the technology of RCC dams is more than two decades old in India, the first RCC dams for Ghatghar Pumped Storage Hydro Project in Maharashtra has been undertaken in 2001-2002. It was conceived to complete the lower dam of 81 meter height and 390 meter length at the crest in two seasons. However, the learning curve took more than estimated time and the dam is expected to be completed in 2006 to 2007 working season.

Using Ordinary Trucks and Paver

for casting the concrete

Using ordinary Roller compacter

For paving the concrete

The concept of RCC involves placement of concrete in the dam on a continuous basis in layers of 300 mm compacted thicknesses. The placement rates can be as high as 600 m3 per hour. Since there is no block joint shuttering, the placement of concrete becomes a continuous operation except for breakdown of plant or inclement weather. Some time is taken in provision of galleries and shafts. These however could be minimized by proper overall planning for provision of galleries and shafts.

Prior to the advent of placing conventional concrete by belt conveyors in dams, the methods for placement adopted were use of cableways (radial, luffing and parallel); revolver cranes; hammer-head cranes and tower cranes. When construction of RCC dams was started, placement was done by conveyor belts supported by dumpers, scrappers and dozers. Alternatively, a complete belt conveyor system to have a geometrical coverage of the dam area was designed.

Construction of RCC Dams

Construction another type of RCC Dams

1- Definition

- ACI 207.5R-89 defines roller compacted concrete (RCC) as concrete compacted by roller compaction. The concrete mixture in its unhardened state must support a roller while being compacted.
- Thus RCC differs from conventional concrete principally in its consistency requirement. For effective consolidation, the concrete mixture must be dry enough to prevent sinking of the vibratory roller equipment but wet enough to permit adequate distribution of the binder mortar in concrete during the mixing and vibratory compaction operations Definition

2- Roller-Compacted Concrete (RCC) USES

2-1: The Right Choice for Concrete Roads

Roller Compacted Concrete (RCC) started in the 1960, when the industry switched to environmentally cleaner, land-based log-sorting methods. Their need to build a strong and massive base, and economical solution was equally important: log-sorting yards can span 64(Donms) or more. RCC met this challenge and has expanded to other heavy-duty applications.

For RCC, economy was the mother of invention. The need for a low-cost, high-volume material for industrial pavements led to its development. Low cost continues to draw engineers, owners, and construction managers to RCC. But today's RCC owes much of its appeal to performance: The strength to withstand heavy and specialized loads; the durability to resist freeze-thaw damage; and the versatility to take on a wide variety of paving applications. From container ports to parking lots, RCC is the right choice for tough duty.

When compared to conventional concrete, RCC placed with these new high-density pavers offers many technical and economic advantages. It is, for example, possible to achieve high quality in terms of strength, durability, and surface finish at relatively low device and personnel costs. The fully mechanical compacting process makes it possible to walk on the surface or lay the second layer with the road paver directly after the high-power compaction screed. Depending on the desired thickness and width of the installation, the concrete can be laid very quickly – from 60 up to 120 meters per hour.

RCC placed with these next generation pavers has a multitude of potential applications in both private and public roadway construction. It can be placed in single or multiple lifts, most typically in 150 or 200 mm (6 or 8-inch) thickness, and is particularly suitable as either a load-carrying base course or a riding surface. These pavers can place the stiff concrete mix simply, efficiently, and economically and are also suitable for industrial and military streets, airports, bus lanes, road-side rest stops, agricultural and forest tracks, cycle paths, footpaths, intersections, yards, parks, parking lots, industrial flooring, and exhibition areas.

RCC is a zero slump concrete that is placed like asphalt. RCC has the same basic ingredients as normal concrete, except RCC is a much drier mix. For road construction the mix is placed through a conventional or a high-density paver and similar to asphalt, is then compacted with a vibratory roller. The mix is so stiff that the vibratory roller can begin compacting immediately behind the paver. RCC requires NO forms, finishing or steel reinforcing. RCC can be placed and compacted in one lift, unlike asphalt which is a multi-lift operation. RCC is also much stronger than asphalt and can be placed thinner to achieve the desired load carrying capability. This labor and thickness reduction combined with the competitive initial material cost compared to asphalt makes RCC extremely cost effective. RCC will not have any potholes, rutting, or shoving and can span soft localized soft sub grades. Our mix design consistently breaks over 8,000 psi compressive strength and 800 – 900 psi flexural strength. RCC will not deform under heavy concentrated loads and will not soften under high temperatures. Builder’s offers a base mix which works great for base and binder asphalt replacement and can be surfaced with asphalt if desired. We also offer a surface mix design which is made up of smaller aggregates for enhanced smoothness.

2-2: The Right Choice for Safe Dams

Dams are a vital, but aging, part of our public works infrastructure. The challenge is to find cost-effective repair and replacement methods without sacrificing safety and reliability.

RCC has three key properties that make it uniquely suited for dams: economy, performance, and high-speed construction. It has the strength and durability of conventional concrete, but at a cost that rivals earth or rock fill construction.

RCC can be used to build new dams or to shore up old ones. It protects dams from over-topping failure, earthquakes, and erosion.

It can be placed quickly and easily with large-volume earth-moving equipment. It's generally transported by dump trucks, spread by bulldozers, and compacted by vibratory rollers.

Sections are built lift-by-lift in successive horizontal layers so the downstream slope resembles a concrete staircase. Once a layer is placed, it can immediately support the earth-moving equipment to place the next layer. After RCC is deposited on the lift surface, small dozers typically spread it in thick layers. Workers also place it with motor graders, spreader boxes, and paving machines.

For existing earth and rock fill dams, RCC acts like an armor plating to protect them from the erosion of high-velocity water flows. RCC can also be used to build new or replacement dams. While it's most economical for large dam projects, RCC is increasingly used to build small dams for water supply and flood control. Not only is RCC more durable than earth or rock fill dams, it's frequently more economical.

RCC has also proven itself in many other types of applications. Older concrete and masonry dams can be buttressed with RCC to increase resistance to earthquake loading and to improve stability to prevent overturning and sliding.

RCC is used as backfill to support conventional concrete spillways. Due to its high resistance to abrasion, RCC is also used to construct stilling basins, build liners for outlet channels, and form grad the first successful application of RCC technology was demonstrated in 1974. The repair of the collapsed intake tunnel of Tarbela Dam proved that the material had more than adequate strength and durability. The maximum placement of 18,000 m3 of RCC in one day, which is still the world's record, was a clear evidence of the potential of this new construction method.

2-3: Typical application areas

The use of RCC for pavements at industrial facilities such as port and intermodal container terminals is particularly appropriate because of the ability to construct low-cost concrete pavements over large areas.

- Bulk material storage
- General cargo storage
- Container terminals
- Road / rail transfer facilities
- Ro-Ro terminals
- Truck parks
- Tank roads and parking
- Sewage sludge stacking
- Composting slabs
- Pre-casting yards

Trucks parking yards made of RCC

3- Attributes of RCC

3-1: The mix for RCC different from the mix of Conventional Concrete

The objective of mix design is to produce an RCC mixture that has sufficient paste volume to coat the aggregates in the mix and to fill in the voids between them. Any of the basic RCC proportioning methods like those based on concrete consistency testing, the solid suspension model, the optimal paste volume method, and soil compaction testing may be used for mix design.

Roller-Compacted Concrete (RCC) uses aggregate sizes often found in conventional concrete. However, the blending of aggregates will be different than that done in case of conventional concrete. Crushed aggregates are preferable in RCC mixes due to the sharp interlocking edges of the particles, which help to reduce segregation, provide higher strengths, and better aggregate interlock at joints and cracks. Gap-graded mixes that are dominated by two or three aggregate sizes are not desirable for RCC. The content of fine particles required is typically higher than that of conventional concrete. Washed aggregates are not required for this type of concrete since a small quantity of non-plastic fines present (2% to 8% material passing a No. 200 sieve) can enhance its properties. This produces a mix that is stable during rolling.

Various Standards /institutes like ACI recommend particular gradings for different roller compacted structures like pavements. Generally use of dense, well-graded blends with a nominal maximum size aggregate (NMSA) not exceeding ¾-inch (19 mm) is recommended in order to help minimize segregation and produce a smooth finished surface.

The moisture content in the mix should be such that the mix is dry enough to support the weight of a vibratory roller yet wet enough to ensure an even distribution of the cement paste.

Compared with conventional concrete, RCC pavement mixes have:

- A lower water content
- A lower paste content
- No air-entrainment, although some admixtures may be used to increase workability and control set time.
- More finer aggregates
- Smaller maximum size coarse aggregate.

3-2: The RCC mix require curing like any type of concrete

Curing is very important for RCC also. Since there is no bleed water in RCC (due to much lesser water content) , the main concern is to prevent its drying to avoid cracking resulting from drying shrinkage & to ensure adequate strength by allowing continuing hydration. Curing also helps in avoiding dusting of surface.

Normally surface of RCC is kept moist for 7 days, or until a curing compound is applied. Due to more open texture surface of RCC, the curing compound application rates are 1.5 to 2 times the application rates used for conventional concrete. Due to large surface area of structures like RCC pavement curing techniques such as plastic sheeting and wet burlap may not be used due to higher cost involved.

4- How can we improve RCC PAVEMENTS?

4-1: Mineral Admixtures

Use of Fly Ash in Roller Compacted Concrete

Engineers and road builders requiring an exceptional concrete for road work will realize significant advantages with Roller Compacted Concrete (RCC). RCC is a zero slump concrete mix with a very low water content. A key component of RCC's exceptional quality is the use of Fly Ash which allows complete compaction. Fly Ash, besides providing the critical size of fines needed to manufacture superior concrete, brings other chemical benefits and advantages to the mix design of concrete. Since the 1980's, use of Roller Compacted Concrete utilizing Fly Ash, has increased as a replacement for conventional concrete mixes, providing significant savings and better roads.

Replacement of Portland cement with Fly Ash has the following benefits:

- Lower installed and life cycle costs versus conventional pavements.
- Provides higher strengths (50 Mpa at 56 days), and greater long term durability.
- Improves workability & place-ability due to the spherical structure of Fly Ash.
- Significantly reduces Alkali Aggregate Reaction (AAR), preventing cracks.
- Improves Sulfate Attack Resistance, preventing expansion cracks, and loss of strength.
- Reduces the Heat of Hydration (by 60%) preventing thermal cracking.
- CO2 is a significant by-product in the manufacture of Portland cement. Every ton of Portland cement that is replaced with Fly Ash in a concrete mixture, prevents one ton of CO2 being released into the atmosphere.

Appropriate production and handling of Fly Ash complements the environmental objectives of utilities and cement manufacturers. This presents an opportunity for collaboration between the utility and cement industries to "green" their respective operations and reduce costs. And as the value, allocation and trading of CO2 emission credits evolve over the next several years, the recycling and responsible use of Fly Ash will contribute substantially to the environmental sustainability of industry operations.

However, in other parts of the world Class C fly ash, slag, and natural pozzolan have also been used.

4-2: Chemical Admixtures

- Air-entraining and water-reducing admixtures are used in RCC compositions that contain higher volume of paste.
- Set-retarding admixtures can extend the time up to which the concrete lift should remain the unhardened, reducing the risk of cold joints with subsequence lift. In RCC mixtures of dry consistency, however, chemical admixtures show rather a limited effectiveness.

4-3: Aggregates

- Aggregates greater than 76 mm in diameter (3 in.) are seldom used in RCC because they can cause problems in spreading and compacting the layer.
- The size of coarse aggregate has a significant influence on the degree of compaction in small layers. This influence is less marked in relatively thicker layers especially when large vibratory rollers are employed.
- The use of material finer than 75 mm (No. 200 mesh sieve) produces a more cohesive mixture by reducing the volume of voids.

4-4: Basic Construction Sequence for Roller Compacted Concrete

- Produced in a pug mill or central batch plant
- Transported by dump trucks
- Placed with an asphalt paver : The thickness of layers generally varies from 8” to 10”
- May be compacted by vibratory or pneumatic-tired rollers

4-5: Durability

- The coefficient of permeability of RCC is a critical parameter for long-term performance of dams, particularly if no impermeable membrane has been used at the upstream face of the dam.
- The construction process of RCC generates porous zones between the lifts where water can percolate. Depending on the mixture proportions and construction process, the coefficient of permeability can very over 8 orders of magnitude.
- For instance, the lean concrete at Willow Creek dam had a coefficient of permeability of 2 x 10-4 m/s, while the coefficient of permeability at Upper Stillwater Dam was 4 x 10-12 m/s. Willow Creek Dam; however, has an impermeable membrane at its upstream face.
- If the moisture content in concrete goes beyond the critical saturation point, the performance of non-air entrained RCC to cycles of freezing and thawing will be poor; however, if the structure does not become saturated, the frost resistance of RCC is satisfactory.
- Air-entrainment of very lean RCC mixtures has not been very successful.

5- Concrete Mixture Proportioning

5-1: Method I

- Uses the principles of soil compaction to produce a lean RCC, where the optimum water content of the concrete is the one that produces the maximum dry density of the mixture.
- This method does not utilizes the conventional concept of minimizing the water-to-cement ratio to maximize the concrete strength; the best compaction gives the best strength, and the best compaction occurs at the most wet mix that will support the operating vibrating roller.
- The overriding criteria for these mixtures are the compressive and shear strength since the dam using this type of concrete typically will have an impermeable upstream face made either by traditional mass concrete or precast panels.

5-2: Method II

- Uses traditional concrete technology methods to produce high-paste RCC mixtures. Upper Stillwater and Elk Creek Dams are examples of dams that were built using this approach. The overriding strength between the lifts and low permeability of criteria for these mixtures are the shear concrete since no protective, impermeable face is used upstream This method does not utilizes the conventional concept of minimizing.

5-3: Laboratory Testing

- RCC is a zero-slump concrete whose properties are strongly dependent on the mixture proportions and on the quality of compaction Concrete is consolidated in the field using vibrating rollers.
- Despite extensive research on this subject, there is as yet no unanimously accepted methodology to simulate the field condition in preparing laboratory samples.
- Construction Practice:

1- The overall planning of a RCC dam is conceptually different from a gravity dam. To minimize thermal stresses, traditional mass concrete is built in separate, monolith blocks.

2- This process is slow but allows great flexibility; if a problem develops in one of the blocks, the construction front moves to another block. RCC dams do not have such luxury.

3- The operation is continuous, building one horizontal lift at a time.

4- There are no special requirements for batching and mixing of RCC which can be produced using the same equipment as for conventional mass concrete.

5- Ready-mixed concrete trucks cannot be used to transport RCC because the zero-slump concrete is too dry and cannot be discharged.

6- To obtain significant economical benefits, special care must be taken in the selection of equipment and construction methods for fast placement and consolidation of RCC.

7- Conveyor systems can be an efficient method of transporting RCC.

8- The success of a RCC dam is often contingent on the correct selection of lift thickness, which depends on the mixture proportions and on the equipment available.

9- If the lift is too thin, the placement rates will be small, thereby reducing the advantages of using RCC.

10- If the lift is too thick, the compaction will not be adequate, creating horizontal layers of higher porosity, thereby compromising the strength and durability of the structure.

11- Normally, the thickness of the lifts ranges from 0.15 to 0.90 m; in the U.S. a lift thickness of 0.3 m is often used.

12- Compaction of the lift is achieved by using a vibrating steel-wheel roller.

13- Compaction of the lift should be performed as soon as possible, typically within 10 minutes after spreading and no more than 40 minutes after mixing.

14- Once adequate compaction is achieved, good curing conditions for the finished surface are essential; the surface should be kept in a moistened condition until the next lift is placed.

15- The dry consistency of RCC results in difficulty in bonding fresh concrete to hardened concrete.

16- This bond can be improved between the lifts by reducing the time of casting the lifts or by increasing the paste content in the mixture.

17- Typically, bedding mixtures contain 360 to 460 kg/m3 of cement, 170 to 220 kg/m3 of fly ash, and 4.75-mm maximum size aggregate.

5-4: Laboratory trial mixtures

- General—it is recommended that a series of mixtures be proportioned and laboratory trial mixed to encompass the potential range of performance requirements. This practice will allow later mixture modifications or adjustments without necessarily repeating the mixture evaluation process. Final adjustments should be made based on full-sized field trial batches, preferably in a test strip or section where workability and compatibility can be observed.
- Visual examination—several characteristics can be determined by visual examination of laboratory prepared trial mixtures. Distribution of aggregate in the mixture, cohesiveness, and tendency for segregation are observable by handling the mixture on the lab floor with shovels. The texture of the mixture (harsh, unworkable, gritty, pasty, and smooth) can be seen and felt with the hand. These characteristics should be recorded for each mixture.
- Testing—Laboratory tests, including temperature, consistency, unit weight, and air content, should be conducted on the fresh RCC produced from each trial mixture. In addition, specimens should be prepared for compressive strength testing at various ages, usually 7, 28, 90, 180 days, and 1 year to indicate the strength gain characteristics of each mixture. These specimens can also be used for determination of static modulus of elasticity and Poisson's ratio at selected ages. Additional specimens should also be fabricated for splitting tensile strength (ASTM C 496) or direct tensile strength at various ages to establish their relationship. to compressive strength, and to provide parameters for use in structural analysis. On major projects, specimens for thermal properties, including adiabatic temperature rise, coefficient of thermal expansion, specific heat, and diffusivity, are usually cast from one or more selected RCC mixtures. Specimens for specialized tests such as creep, tensile strain capacity, and shear strength may also be cast from these mixtures. Many commercial laboratories are not equipped to conduct these tests, and special arrangements may be required with the Corps of Engineers, U.S. Bureau of Reclamation, or universities that have the equipment and facilities for this work.

6-Features

- High flexural strength (500 to 1000 psi) (3.5 MPa to 7.0 MPa)
- High compressive strength (4,000 to 10,000 psi) (28 MPa to 69 MPa)
- High shear strength
- High density, low absorption
- Low water content, low water/cement ratio
- Aggregate interlock
- No steel reinforcing or dowels

- No forms or finishing
- No formed or sawed joints
- Hard, durable, light-colored surface

7-Benefits

- Supports heavy, repetitive loads without failure and spans localized soft subgrade areas, which reduces maintenance costs and down time.
- Withstands high concentrated loads and impacts from heavy industrial, military, and mining applications.
- Eliminates rutting and subsequent repairs.
- Provides excellent durability, even under freeze-thaw conditions; eliminates seepage through pavement.
- Increases strength, reduces permeability, and enhances durability and resistance to chemical attack.
- Provides high shear resistance at joints and uncontrolled cracks to prevent vertical displacement or faulting.
- Speeds and simplifies construction, reduces costs.
- Speeds construction, reduces cost, minimizes labor.
- Speeds construction, reduces cost. (To enhance appearance, joints can be sawn into RCC pavement.)
- Resists abrasion, eliminates need for surface course and reduces cost. The light color reduces lighting requirements for parking and storage areas

8-Limitations

- Aesthetics - RCC does not have the same appearance as other types of concrete. It is NOT as pretty and smooth as regular concrete.
- Rougher Surface Texture - The mix design and construction methods that make roller compacted concrete so fast, easy, cheap, and durable also create a surface texture that gives it a characteristic coarse finish.
- Limited to low-speed traffic - Due to the nature of its surface, RCC is not appropriate for all types of traffic. Vehicles traveling at high speeds would experience a bumpy ride. That makes it better for applications where strength and durability are needed instead of speed.
- Leakage may happen in Dams Due to the nature of its surfaces and the way of the constructions layer bay layers in the dams’ leakage of water may be happen and treatments are needed in the ends extra cost may be needed.
- Creep

1- The long-term deformation of RCC depends on the amount and the type of aggregate, the water to- cement ratio, the age of loading, and the duration of loading.

2- RCC with lower compressive strength and lower elastic modulus will normally show high creep which is a critical factor in determining the stress relaxation when thermal strain is restrained.

3- Lean concrete with large amounts of fines also shows high creep.

9-DESIGN OF RCC DAMS

The use of RCC offers a wide range of economical and safe design alternatives to conventional concrete and embankment dams. Placing RCC in lifts that are compacted by vibratory rollers does not change the basic design concepts for dams, locks or other massive structures. A detailed treatment of dam design principles and formulas is not addressed in this item.

Important considerations that must be addressed include the basic purpose of the dam and the owner's requirements for cost, schedule, appearance, watertightness, operation and maintenance.

A review of these considerations should determine the selection of the proper RCC mixture, lift surface treatments, facing treatments and the basic configuration of the dam. The overall design should be kept as simple as possible to fully capture the advantages of rapid construction using RCC technology. Any organization or individual may adopt practices or design criteria which are different than the guidelines contained herein the state of the art in the design of RCC dams and other massive structures. It is not purported to be the standard for design but they should obtained the data bellows:-

1- Dam section considerations

2- Stability especially (*Shear-friction factor* , Design values for tensile and shear strength parameters)

3- Temperature studies and control

4- **Contraction joints**

5- **Galleries and adits**

6- **Facing design and seepage control(***Upstream facing*, *Downstream facing* & *Seepage control*)

7- **Spillways**

8- **Outlet works**

9- Tensile strength—Tensile strength of RCC is required for design purposes, including dynamic loading and in the thermal analysis. The ratios of tensile-to-compressive strength for parent (un jointed) RCC mixtures have typically ranged from approximately 5 to 15%, depending on aggregate quality, strength age, and test method.

10- Conclusion

A growing niche market for roller compacted concrete has prompted manufacturers to offer solutions.

Increased demand for roller compacted concrete (RCC) machines in certain applications mean that this is now a growing market, with manufacturers having developed new machines for this sector. RCC comprises uncrushed and/or crushed aggregate, hydraulic binders and may also contain concrete additives. It is mixed in a concrete mixing plant on or near the job site and one of its main benefits is that it takes significantly less time to cure than conventional concrete. As a result it can carry traffic shortly after being laid and also gives good structural integrity. The mix is transported by conventional feed vehicles and transferred to a paver, with the concrete layer then being compacted with rollers.

The paving method has been used for some years but technical developments in recent times have broadened its range of applications and steadily widened its use. This approach has been used successfully for some time in large open areas such as logistics facilities to provide a surface that can carry high load capacities without rutting or other fatigue issues. The more recent development mean that this technology is also being used in residential and city streets, pedestrian walkways, intersections and interstate ramps. According to the moisture content of RCC is crucial for achieving maximum pre compaction values. If the material contains too little water, efficient compaction may prove, while if it contains too much water, the screed could sink into the mix. As a result, the moisture content should be checked carefully and tests of the mix should be carried out at the site. RCC is stiff enough to be compacted with vibratory rollers, however, the number of roller passes must be kept to a minimum in order to deliver stability, evenness and surface structure.

Asphalt pavers from many major manufacturers can be used in an RCC application. However, the nature of an RCC job is tough on an asphalt paver as concrete is typically more abrasive than asphalt and for this reason many Factories opted to develop its own unit that is designed for harsh, zero-slump mixes. These Factories developed the machine to provide customers with a further paving option and this model is now proving itself on-site with contractors. At present the machine is offered in the US market only, and is not available internationally however.

In Iraq and Kurdistan region especially, new generation of Reinforced concrete roads are constructed and under constructions to prevents the failures in the roads due to the large movements of heavy trucks due to the large commercial exchanges between the world and Iraqi states and Kurdistan region states especially of a extra cost by using 50-200 kg steel reinforcement and extra quantity of cement by (180 -280 kg) in each cubic meter of concrete used or will used in the roads and dams.

By simple calculations we can see how much costs and time will be saved when using Roller-compacted concrete for roads and dams when we compares.

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11- Important data (tables ,images and curves) collected from executed projects(dam projects)

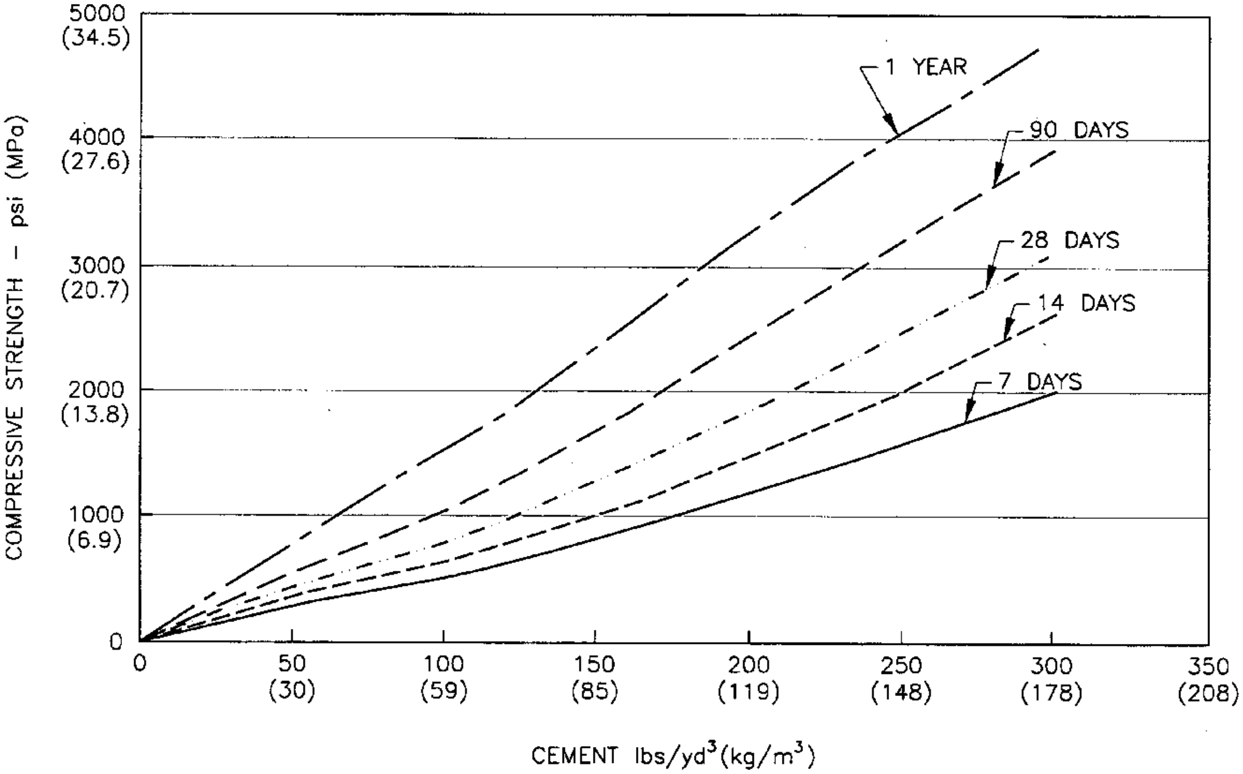


Fig. 1—RCC strength curves that can be developed from tests conducted on concretes with varying proportions of Cement for good quality aggregates.

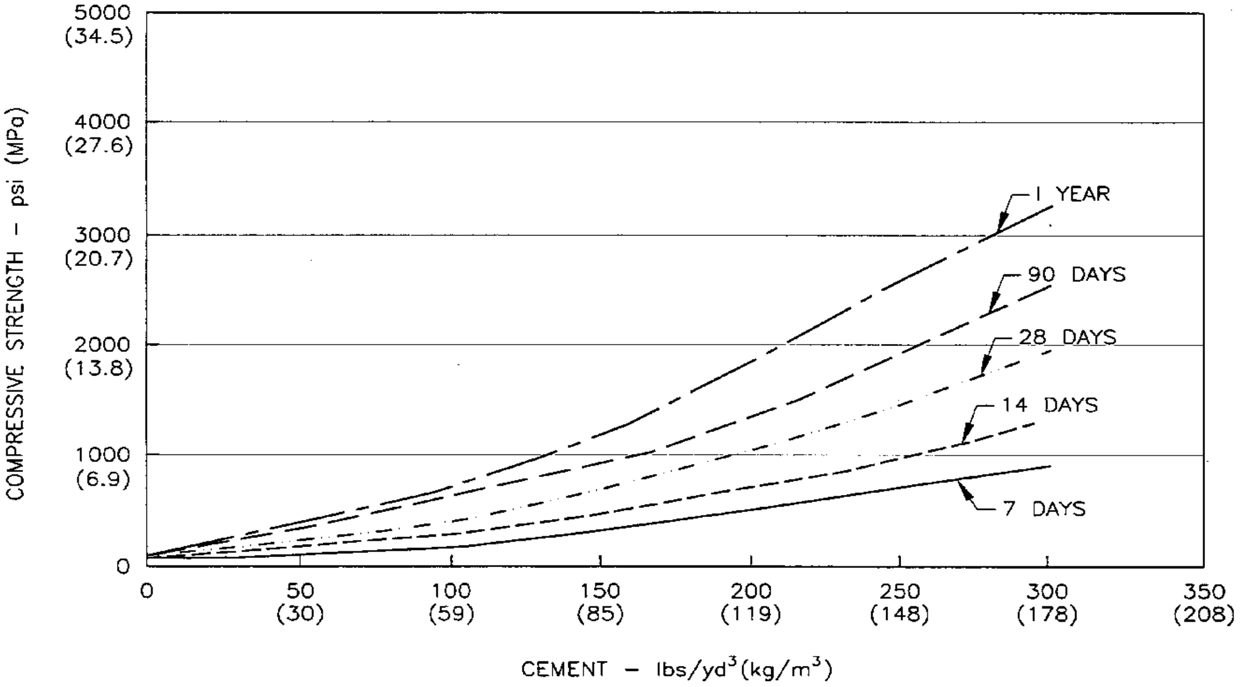


Fig. 2—RCC strength curves developed for lesser quality Aggregates.

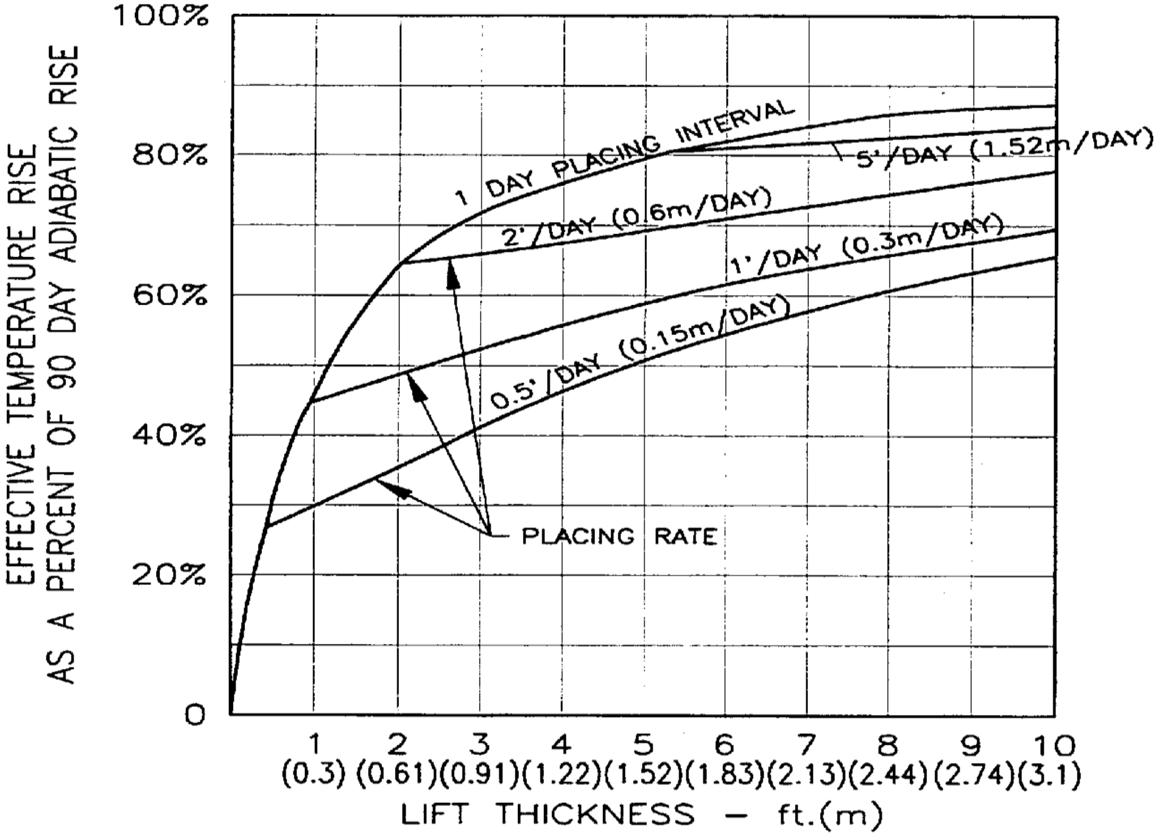


Fig.3—Generalized effect of placing rates and lift height on temperature for conventional conditions (Cannon, *1972)*.

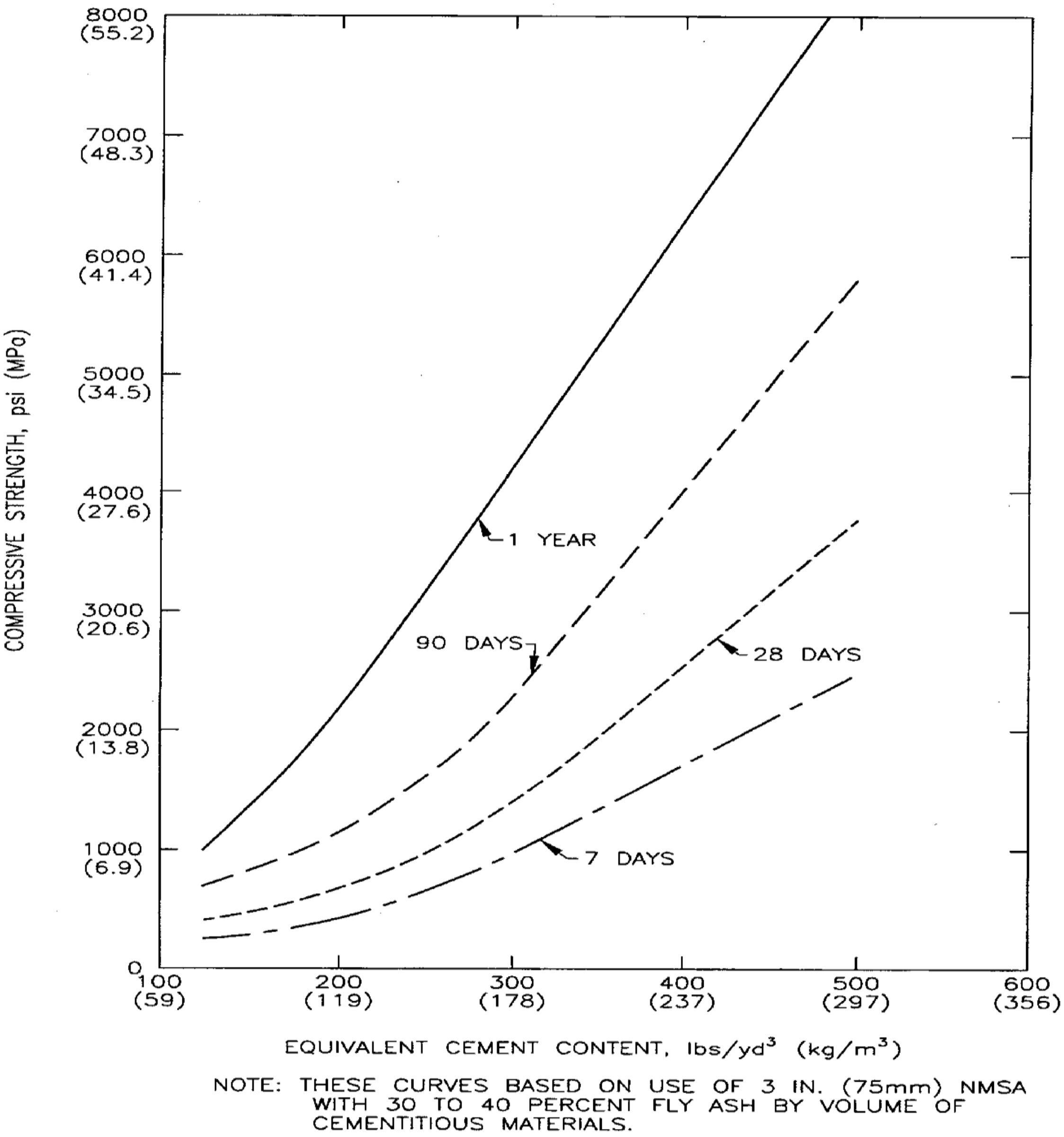
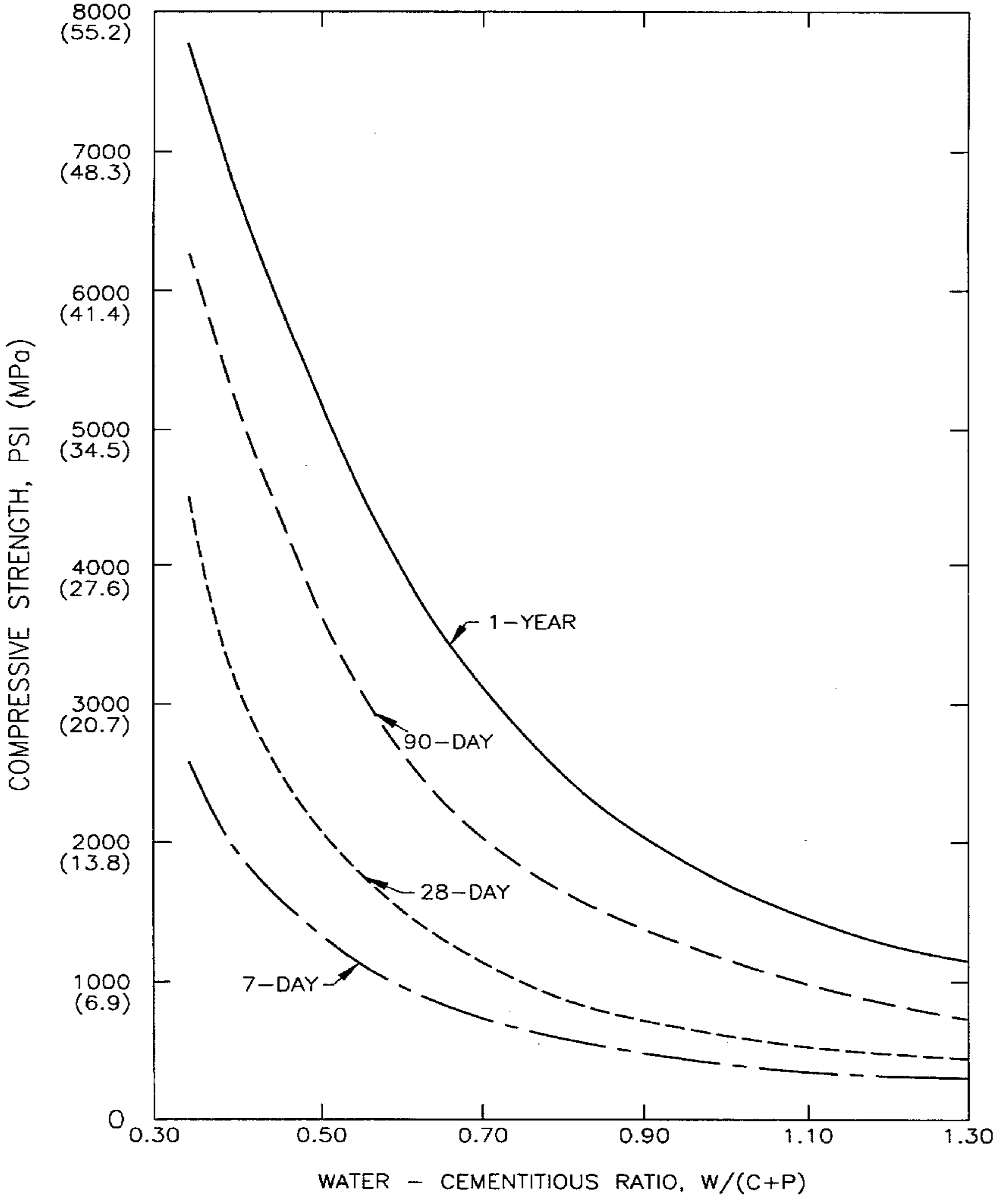


Fig. 4—Equivalent cement content versus compressive strength (USACE, 1992).



NOTE: THESE CURVES BASED ON USE OF 3 IN. (75mm) NMSA WITH 30 TO 40 PERCENT FLY ASH BY VOLUME OF CEMENTITIOUS MATERIALS.

Fig. 5—Compressive strength versus w/cm (USACE, 1992).

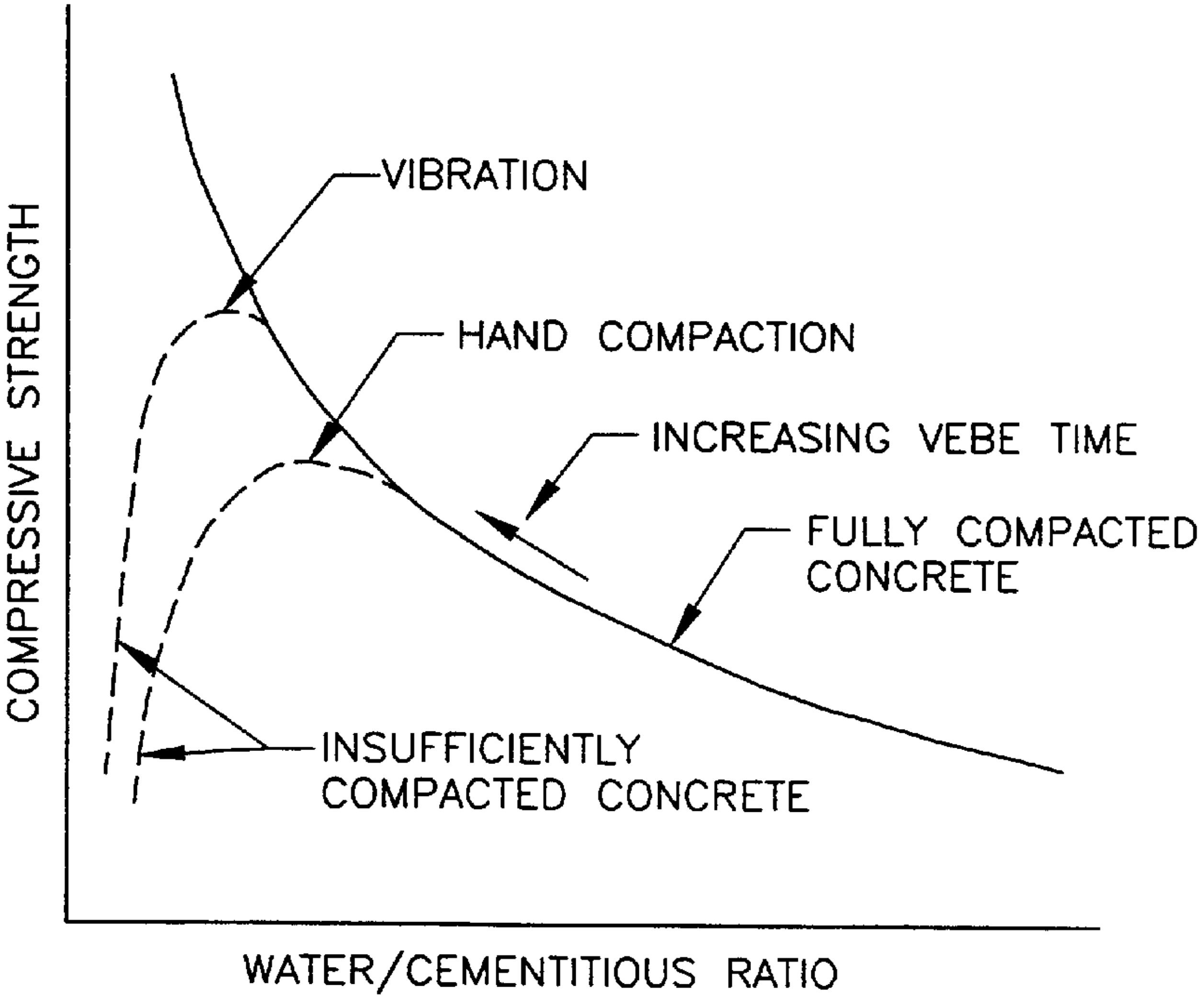
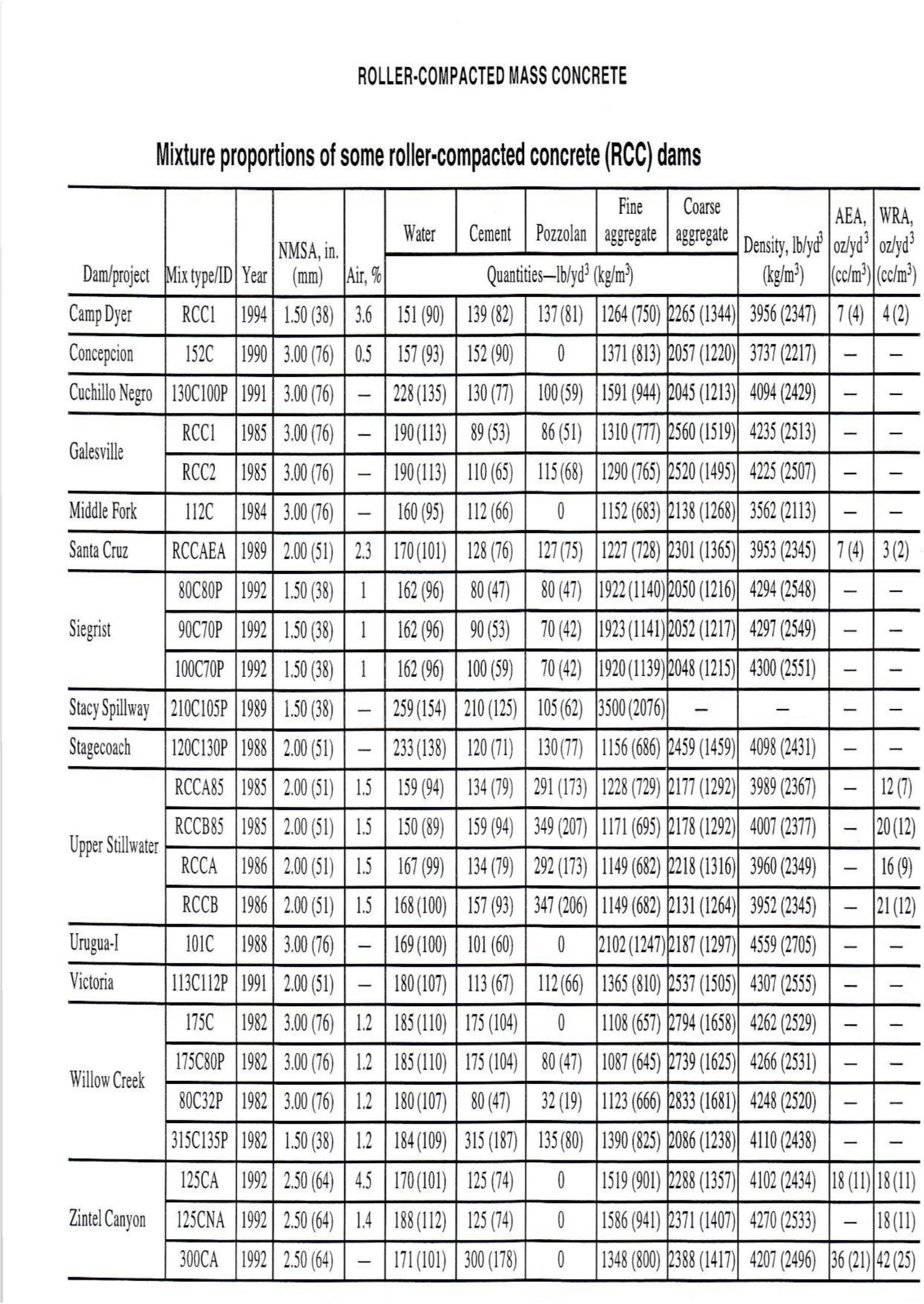


Fig. 6—General relationship between compressive strength and w/cm.



ROLLER-COMPACTED MASS CONCRETE

Mixture proportions of some roller-compacted concrete (RCC) dams

Dam/project	Mix type/ID	Year	NMSA, in. (mm)	Air, %	Water	Cement	Pozzolan	Fine aggregate	Coarse aggregate	Density, lb/yd^3 (kg/m^3)	AEA, oz/yd^3 (cc/m^3)	WRA, oz/yd^3 (cc/m^3)
					Quantities—lb/yd^3 (kg/m^3)							
Camp Dyer	RCC1	1994	1.50 (38)	3.6	151 (90)	139 (82)	137 (81)	1264 (750)	2265 (1344)	3956 (2347)	7 (4)	4 (2)
Concepcion	152C	1990	3.00 (76)	0.5	157 (93)	152 (90)	0	1371 (813)	2057 (1220)	3737 (2217)	—	—
Cuchillo Negro	130C100P	1991	3.00 (76)	—	228 (135)	130 (77)	100 (59)	1591 (944)	2045 (1213)	4094 (2429)	—	—
Galesville	RCC1	1985	3.00 (76)	—	190 (113)	89 (53)	86 (51)	1310 (777)	2560 (1519)	4235 (2513)	—	—
	RCC2	1985	3.00 (76)	—	190 (113)	110 (65)	115 (68)	1290 (765)	2520 (1495)	4225 (2507)	—	—
Middle Fork	112C	1984	3.00 (76)	—	160 (95)	112 (66)	0	1152 (683)	2138 (1268)	3562 (2113)	—	—
Santa Cruz	RCCAEA	1989	2.00 (51)	2.3	170 (101)	128 (76)	127 (75)	1227 (728)	2301 (1365)	3953 (2345)	7 (4)	3 (2)
Siegrist	80C80P	1992	1.50 (38)	1	162 (96)	80 (47)	80 (47)	1922 (1140)	2050 (1216)	4294 (2548)	—	—
	90C70P	1992	1.50 (38)	1	162 (96)	90 (53)	70 (42)	1923 (1141)	2052 (1217)	4297 (2549)	—	—
	100C70P	1992	1.50 (38)	1	162 (96)	100 (59)	70 (42)	1920 (1139)	2048 (1215)	4300 (2551)	—	—
Stacy Spillway	210C105P	1989	1.50 (38)	—	259 (154)	210 (125)	105 (62)	3500 (2076)	—	—	—	—
Stagecoach	120C130P	1988	2.00 (51)	—	233 (138)	120 (71)	130 (77)	1156 (686)	2459 (1459)	4098 (2431)	—	—
Upper Stillwater	RCCA85	1985	2.00 (51)	1.5	159 (94)	134 (79)	291 (173)	1228 (729)	2177 (1292)	3989 (2367)	—	12 (7)
	RCCB85	1985	2.00 (51)	1.5	150 (89)	159 (94)	349 (207)	1171 (695)	2178 (1292)	4007 (2377)	—	20 (12)
	RCCA	1986	2.00 (51)	1.5	167 (99)	134 (79)	292 (173)	1149 (682)	2218 (1316)	3960 (2349)	—	16 (9)
	RCCB	1986	2.00 (51)	1.5	168 (100)	157 (93)	347 (206)	1149 (682)	2131 (1264)	3952 (2345)	—	21 (12)
Urugua-I	101C	1988	3.00 (76)	—	169 (100)	101 (60)	0	2102 (1247)	2187 (1297)	4559 (2705)	—	—
Victoria	113C112P	1991	2.00 (51)	—	180 (107)	113 (67)	112 (66)	1365 (810)	2537 (1505)	4307 (2555)	—	—
Willow Creek	175C	1982	3.00 (76)	1.2	185 (110)	175 (104)	0	1108 (657)	2794 (1658)	4262 (2529)	—	—
	175C80P	1982	3.00 (76)	1.2	185 (110)	175 (104)	80 (47)	1087 (645)	2739 (1625)	4266 (2531)	—	—
	80C32P	1982	3.00 (76)	1.2	180 (107)	80 (47)	32 (19)	1123 (666)	2833 (1681)	4248 (2520)	—	—
	315C135P	1982	1.50 (38)	1.2	184 (109)	315 (187)	135 (80)	1390 (825)	2086 (1238)	4110 (2438)	—	—
Zintel Canyon	125CA	1992	2.50 (64)	4.5	170 (101)	125 (74)	0	1519 (901)	2288 (1357)	4102 (2434)	18 (11)	18 (11)
	125CNA	1992	2.50 (64)	1.4	188 (112)	125 (74)	0	1586 (941)	2371 (1407)	4270 (2533)	—	18 (11)
	300CA	1992	2.50 (64)	—	171 (101)	300 (178)	0	1348 (800)	2388 (1417)	4207 (2496)	36 (21)	42 (25)

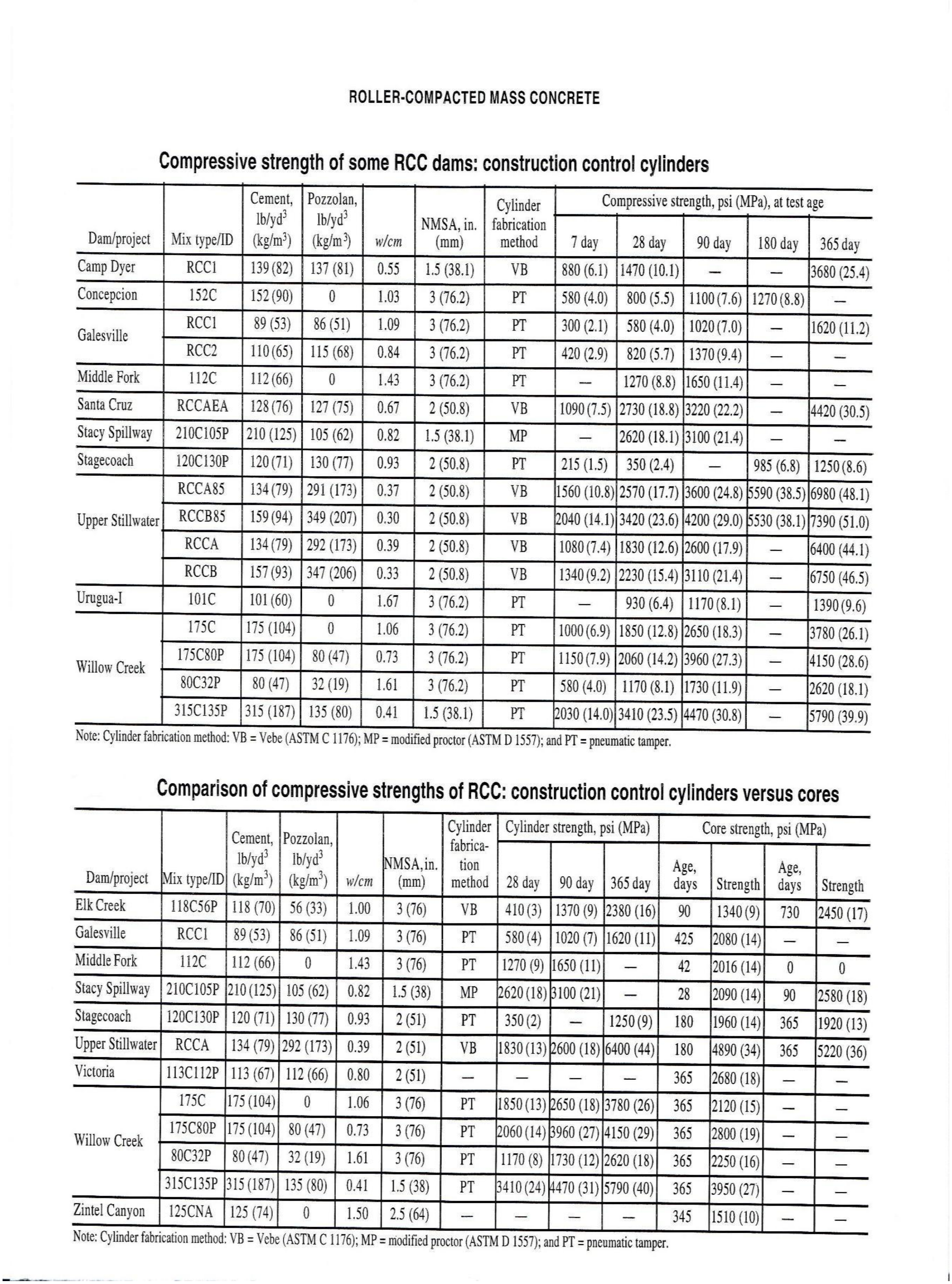
Table 1

Combined aggregate gradings for RCC from various projects in U.S.

Sieve size	Willow Creek	Upper Stillwater	Christian Siegrist	Zintel Canyon	Stagecoach	Elk Creek
4 in. (100 mm)	—	—	—	—	—	—
3 in. (75 mm)	100	—	—	—	—	100
2.5 in. (62 mm)	—	—	—	100	—	96
2 in. (50 mm)	90	100	—	98	100	86
1.5 in. (37.5 mm)	80	95	100	91	95	76
1 in. (25 mm)	62	—	99	77	82	64
0.75 in. (19 mm)	54	66	91	70	69	58
3/8 in. (9.5 mm)	42	45	60	50	52	51
No. 4 (4.75 mm)	30	35	49	39	40	41
No. 8 (2.36 mm)	23	26	38	25	32	34
No. 16 (1.18 mm)	17	21	23	18	25	31
No. 30 (0.60 mm)	13	17	14	15	15	21
No. 50 (0.30 mm)	9	10	10	12	10	15
No. 100 (0.15 mm)	7	2	6	11	8	10
No. 200 (0.075 mm)	5	0	5	9	5	7
C + *P* lb/cy	80 + 32	134 + 291	100 + 70	125 + 0	120 + 130	118 + 56
Total fines*	20%	21%	19%	21%	—	21%
Workability	Poor	Excellent	Excellent	Excellent	Good	Excellent

*Total fines = all materials in full mixture with particle size smaller than No. 200 sieve.

Table 2



Compressive strength of some RCC dams: construction control cylinders

Dam/project	Mix type/ID	Cement, lb/yd^3 (kg/m^3)	Pozzolan, lb/yd^3 (kg/m^3)	*w/cm*	NMSA, in. (mm)	Cylinder fabrication method	Compressive strength, psi (MPa), at test age				
							7 day	28 day	90 day	180 day	365 day
Camp Dyer	RCC1	139 (82)	137 (81)	0.55	1.5 (38.1)	VB	880 (6.1)	1470 (10.1)	—	—	3680 (25.4)
Concepcion	152C	152 (90)	0	1.03	3 (76.2)	PT	580 (4.0)	800 (5.5)	1100 (7.6)	1270 (8.8)	—
Galesville	RCC1	89 (53)	86 (51)	1.09	3 (76.2)	PT	300 (2.1)	580 (4.0)	1020 (7.0)	—	1620 (11.2)
	RCC2	110 (65)	115 (68)	0.84	3 (76.2)	PT	420 (2.9)	820 (5.7)	1370 (9.4)	—	—
Middle Fork	112C	112 (66)	0	1.43	3 (76.2)	PT	—	1270 (8.8)	1650 (11.4)	—	—
Santa Cruz	RCCAEA	128 (76)	127 (75)	0.67	2 (50.8)	VB	1090 (7.5)	2730 (18.8)	3220 (22.2)	—	4420 (30.5)
Stacy Spillway	210C105P	210 (125)	105 (62)	0.82	1.5 (38.1)	MP	—	2620 (18.1)	3100 (21.4)	—	—
Stagecoach	120C130P	120 (71)	130 (77)	0.93	2 (50.8)	PT	215 (1.5)	350 (2.4)	—	985 (6.8)	1250 (8.6)
Upper Stillwater	RCCA85	134 (79)	291 (173)	0.37	2 (50.8)	VB	1560 (10.8)	2570 (17.7)	3600 (24.8)	5590 (38.5)	6980 (48.1)
	RCCB85	159 (94)	349 (207)	0.30	2 (50.8)	VB	2040 (14.1)	3420 (23.6)	4200 (29.0)	5530 (38.1)	7390 (51.0)
	RCCA	134 (79)	292 (173)	0.39	2 (50.8)	VB	1080 (7.4)	1830 (12.6)	2600 (17.9)	—	6400 (44.1)
	RCCB	157 (93)	347 (206)	0.33	2 (50.8)	VB	1340 (9.2)	2230 (15.4)	3110 (21.4)	—	6750 (46.5)
Urugua-I	101C	101 (60)	0	1.67	3 (76.2)	PT	—	930 (6.4)	1170 (8.1)	—	1390 (9.6)
Willow Creek	175C	175 (104)	0	1.06	3 (76.2)	PT	1000 (6.9)	1850 (12.8)	2650 (18.3)	—	3780 (26.1)
	175C80P	175 (104)	80 (47)	0.73	3 (76.2)	PT	1150 (7.9)	2060 (14.2)	3960 (27.3)	—	4150 (28.6)
	80C32P	80 (47)	32 (19)	1.61	3 (76.2)	PT	580 (4.0)	1170 (8.1)	1730 (11.9)	—	2620 (18.1)
	315C135P	315 (187)	135 (80)	0.41	1.5 (38.1)	PT	2030 (14.0)	3410 (23.5)	4470 (30.8)	—	5790 (39.9)

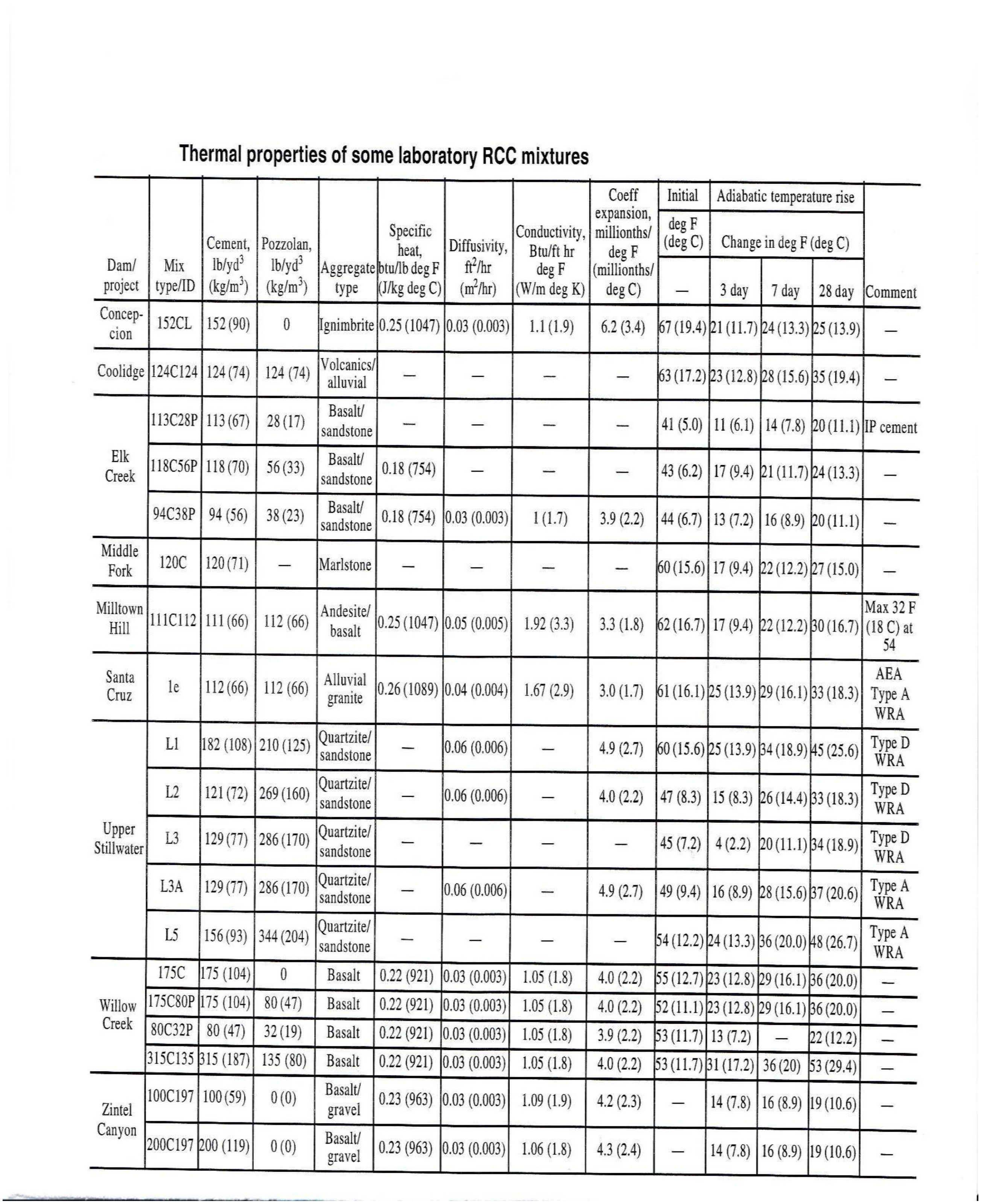
Note: Cylinder fabrication method: VB = Vebe (ASTM C 1176); MP = modified proctor (ASTM D 1557); and PT = pneumatic tamper.

Comparison of compressive strengths of RCC: construction control cylinders versus cores

Dam/project	Mix type/ID	Cement, lb/yd^3 (kg/m^3)	Pozzolan, lb/yd^3 (kg/m^3)	*w/cm*	NMSA, in. (mm)	Cylinder fabrication method	Cylinder strength, psi (MPa)			Core strength, psi (MPa)			
							28 day	90 day	365 day	Age, days	Strength	Age, days	Strength
Elk Creek	118C56P	118 (70)	56 (33)	1.00	3 (76)	VB	410 (3)	1370 (9)	2380 (16)	90	1340 (9)	730	2450 (17)
Galesville	RCC1	89 (53)	86 (51)	1.09	3 (76)	PT	580 (4)	1020 (7)	1620 (11)	425	2080 (14)	—	—
Middle Fork	112C	112 (66)	0	1.43	3 (76)	PT	1270 (9)	1650 (11)	—	42	2016 (14)	0	0
Stacy Spillway	210C105P	210 (125)	105 (62)	0.82	1.5 (38)	MP	2620 (18)	3100 (21)	—	28	2090 (14)	90	2580 (18)
Stagecoach	120C130P	120 (71)	130 (77)	0.93	2 (51)	PT	350 (2)	—	1250 (9)	180	1960 (14)	365	1920 (13)
Upper Stillwater	RCCA	134 (79)	292 (173)	0.39	2 (51)	VB	1830 (13)	2600 (18)	6400 (44)	180	4890 (34)	365	5220 (36)
Victoria	113C112P	113 (67)	112 (66)	0.80	2 (51)	—	—	—	—	365	2680 (18)	—	—
Willow Creek	175C	175 (104)	0	1.06	3 (76)	PT	1850 (13)	2650 (18)	3780 (26)	365	2120 (15)	—	—
	175C80P	175 (104)	80 (47)	0.73	3 (76)	PT	2060 (14)	3960 (27)	4150 (29)	365	2800 (19)	—	—
	80C32P	80 (47)	32 (19)	1.61	3 (76)	PT	1170 (8)	1730 (12)	2620 (18)	365	2250 (16)	—	—
	315C135P	315 (187)	135 (80)	0.41	1.5 (38)	PT	3410 (24)	4470 (31)	5790 (40)	365	3950 (27)	—	—
Zintel Canyon	125CNA	125 (74)	0	1.50	2.5 (64)	—	—	—	—	345	1510 (10)	—	—

Note: Cylinder fabrication method: VB = Vebe (ASTM C 1176); MP = modified proctor (ASTM D 1557); and PT = pneumatic tamper.

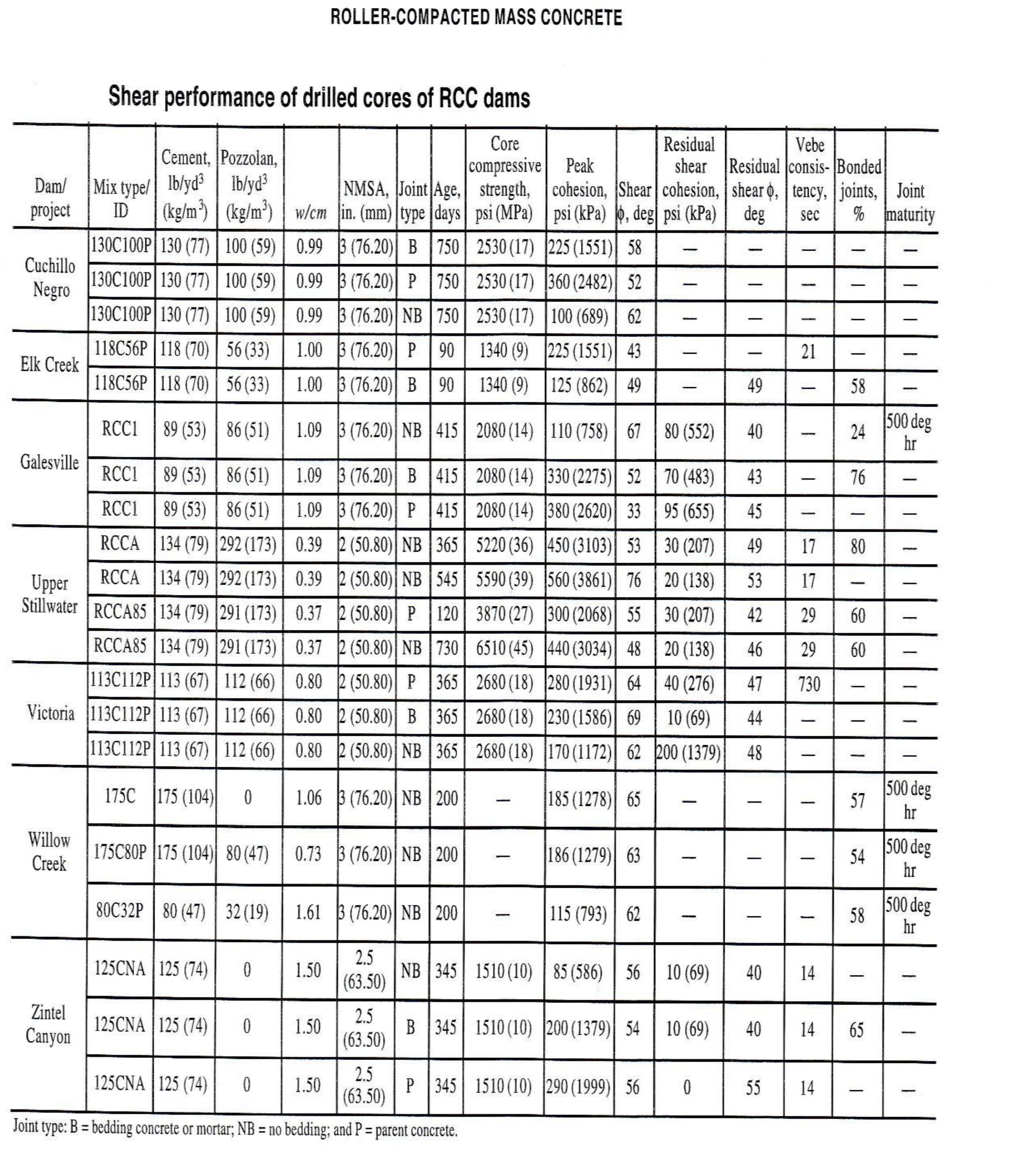
Table 3&4



Thermal properties of some laboratory RCC mixtures

Dam/ project	Mix type/ID	Cement, lb/yd^3 (kg/m^3)	Pozzolan, lb/yd^3 (kg/m^3)	Aggregate type	Specific heat, btu/lb deg F (J/kg deg C)	Diffusivity, ft^2/hr (m^2/hr)	Conductivity, Btu/ft hr deg F (W/m deg K)	Coeff expansion, millionths/ deg F (millionths/ deg C)	Initial	Adiabatic temperature rise			Comment
									deg F (deg C)	Change in deg F (deg C)			
									—	3 day	7 day	28 day	
Concepcion	152CL	152 (90)	0	Ignimbrite	0.25 (1047)	0.03 (0.003)	1.1 (1.9)	6.2 (3.4)	67 (19.4)	21 (11.7)	24 (13.3)	25 (13.9)	—
Coolidge	124C124	124 (74)	124 (74)	Volcanics/ alluvial	—	—	—	—	63 (17.2)	23 (12.8)	28 (15.6)	35 (19.4)	—
Elk Creek	113C28P	113 (67)	28 (17)	Basalt/ sandstone	—	—	—	—	41 (5.0)	11 (6.1)	14 (7.8)	20 (11.1)	IP cement
	118C56P	118 (70)	56 (33)	Basalt/ sandstone	0.18 (754)	—	—	—	43 (6.2)	17 (9.4)	21 (11.7)	24 (13.3)	—
	94C38P	94 (56)	38 (23)	Basalt/ sandstone	0.18 (754)	0.03 (0.003)	1 (1.7)	3.9 (2.2)	44 (6.7)	13 (7.2)	16 (8.9)	20 (11.1)	—
Middle Fork	120C	120 (71)	—	Marlstone	—	—	—	—	60 (15.6)	17 (9.4)	22 (12.2)	27 (15.0)	—
Milltown Hill	111C112	111 (66)	112 (66)	Andesite/ basalt	0.25 (1047)	0.05 (0.005)	1.92 (3.3)	3.3 (1.8)	62 (16.7)	17 (9.4)	22 (12.2)	30 (16.7)	Max 32 F (18 C) at 54
Santa Cruz	1e	112 (66)	112 (66)	Alluvial granite	0.26 (1089)	0.04 (0.004)	1.67 (2.9)	3.0 (1.7)	61 (16.1)	25 (13.9)	29 (16.1)	33 (18.3)	AEA Type A WRA
Upper Stillwater	L1	182 (108)	210 (125)	Quartzite/ sandstone	—	0.06 (0.006)	—	4.9 (2.7)	60 (15.6)	25 (13.9)	34 (18.9)	45 (25.6)	Type D WRA
	L2	121 (72)	269 (160)	Quartzite/ sandstone	—	0.06 (0.006)	—	4.0 (2.2)	47 (8.3)	15 (8.3)	26 (14.4)	33 (18.3)	Type D WRA
	L3	129 (77)	286 (170)	Quartzite/ sandstone	—	—	—	—	45 (7.2)	4 (2.2)	20 (11.1)	34 (18.9)	Type D WRA
	L3A	129 (77)	286 (170)	Quartzite/ sandstone	—	0.06 (0.006)	—	4.9 (2.7)	49 (9.4)	16 (8.9)	28 (15.6)	37 (20.6)	Type A WRA
	L5	156 (93)	344 (204)	Quartzite/ sandstone	—	—	—	—	54 (12.2)	24 (13.3)	36 (20.0)	48 (26.7)	Type A WRA
Willow Creek	175C	175 (104)	0	Basalt	0.22 (921)	0.03 (0.003)	1.05 (1.8)	4.0 (2.2)	55 (12.7)	23 (12.8)	29 (16.1)	36 (20.0)	—
	175C80P	175 (104)	80 (47)	Basalt	0.22 (921)	0.03 (0.003)	1.05 (1.8)	4.0 (2.2)	52 (11.1)	23 (12.8)	29 (16.1)	36 (20.0)	—
	80C32P	80 (47)	32 (19)	Basalt	0.22 (921)	0.03 (0.003)	1.05 (1.8)	3.9 (2.2)	53 (11.7)	13 (7.2)	—	22 (12.2)	—
	315C135	315 (187)	135 (80)	Basalt	0.22 (921)	0.03 (0.003)	1.05 (1.8)	4.0 (2.2)	53 (11.7)	31 (17.2)	36 (20)	53 (29.4)	—
Zintel Canyon	100C197	100 (59)	0 (0)	Basalt/ gravel	0.23 (963)	0.03 (0.003)	1.09 (1.9)	4.2 (2.3)	—	14 (7.8)	16 (8.9)	19 (10.6)	—
	200C197	200 (119)	0 (0)	Basalt/ gravel	0.23 (963)	0.03 (0.003)	1.06 (1.8)	4.3 (2.4)	—	14 (7.8)	16 (8.9)	19 (10.6)	—

Table 5



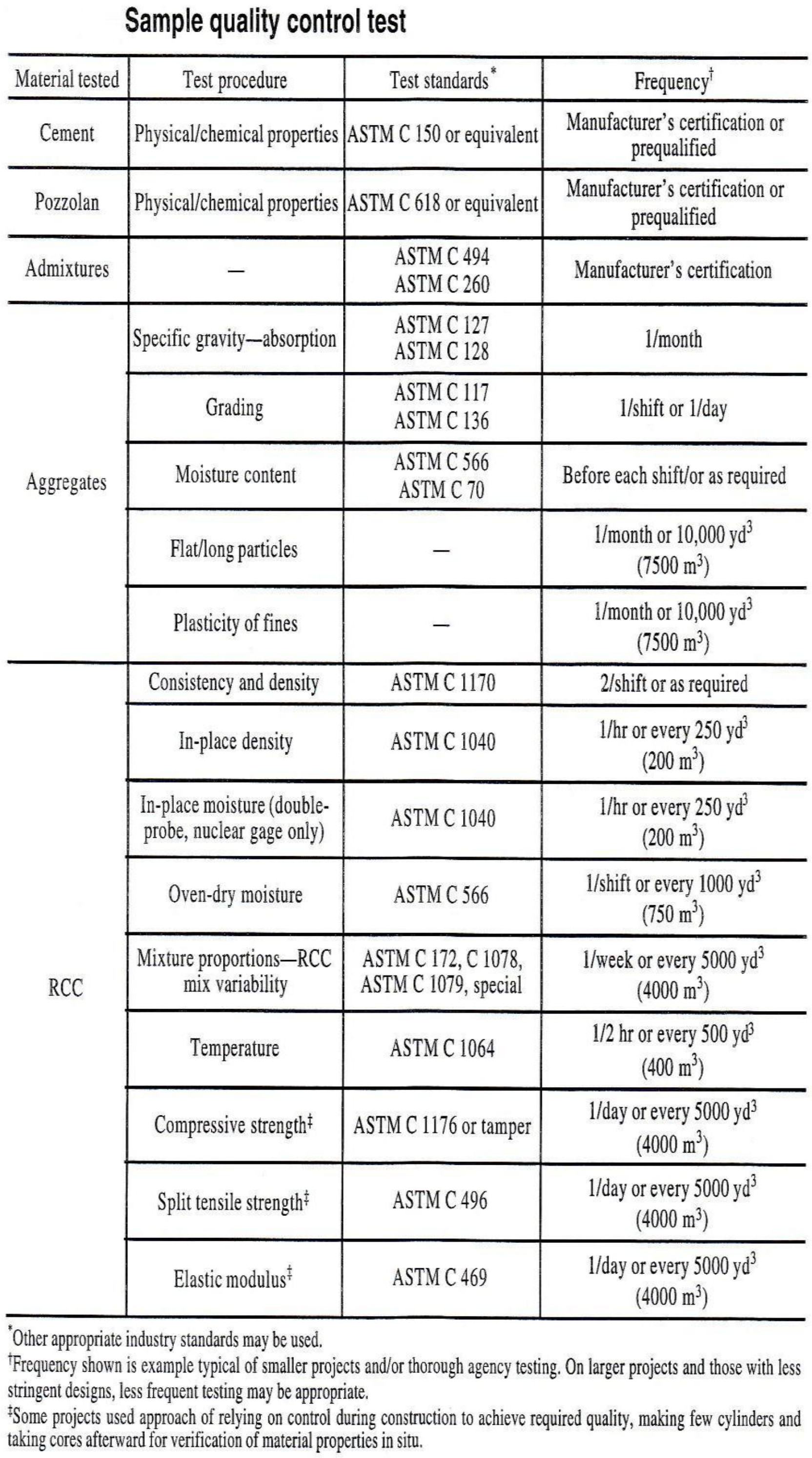
ROLLER-COMPACTED MASS CONCRETE

Shear performance of drilled cores of RCC dams

Dam/ project	Mix type/ ID	Cement, lb/yd^3 (kg/m^3)	Pozzolan, lb/yd^3 (kg/m^3)	*w/cm*	NMSA, in. (mm)	Joint type	Age, days	Core compressive strength, psi (MPa)	Peak cohesion, psi (kPa)	Shear ϕ, deg	Residual shear cohesion, psi (kPa)	Residual shear ϕ, deg	Vebe consis-tency, sec	Bonded joints, %	Joint maturity
Cuchillo Negro	130C100P	130 (77)	100 (59)	0.99	3 (76.20)	B	750	2530 (17)	225 (1551)	58	—	—	—	—	—
	130C100P	130 (77)	100 (59)	0.99	3 (76.20)	P	750	2530 (17)	360 (2482)	52	—	—	—	—	—
	130C100P	130 (77)	100 (59)	0.99	3 (76.20)	NB	750	2530 (17)	100 (689)	62	—	—	—	—	—
Elk Creek	118C56P	118 (70)	56 (33)	1.00	3 (76.20)	P	90	1340 (9)	225 (1551)	43	—	—	21	—	—
	118C56P	118 (70)	56 (33)	1.00	3 (76.20)	B	90	1340 (9)	125 (862)	49	—	49	—	58	—
Galesville	RCC1	89 (53)	86 (51)	1.09	3 (76.20)	NB	415	2080 (14)	110 (758)	67	80 (552)	40	—	24	500 deg hr
	RCC1	89 (53)	86 (51)	1.09	3 (76.20)	B	415	2080 (14)	330 (2275)	52	70 (483)	43	—	76	—
	RCC1	89 (53)	86 (51)	1.09	3 (76.20)	P	415	2080 (14)	380 (2620)	33	95 (655)	45	—	—	—
Upper Stillwater	RCCA	134 (79)	292 (173)	0.39	2 (50.80)	NB	365	5220 (36)	450 (3103)	53	30 (207)	49	17	80	—
	RCCA	134 (79)	292 (173)	0.39	2 (50.80)	NB	545	5590 (39)	560 (3861)	76	20 (138)	53	17	—	—
	RCCA85	134 (79)	291 (173)	0.37	2 (50.80)	P	120	3870 (27)	300 (2068)	55	30 (207)	42	29	60	—
	RCCA85	134 (79)	291 (173)	0.37	2 (50.80)	NB	730	6510 (45)	440 (3034)	48	20 (138)	46	29	60	—
Victoria	113C112P	113 (67)	112 (66)	0.80	2 (50.80)	P	365	2680 (18)	280 (1931)	64	40 (276)	47	730	—	—
	113C112P	113 (67)	112 (66)	0.80	2 (50.80)	B	365	2680 (18)	230 (1586)	69	10 (69)	44	—	—	—
	113C112P	113 (67)	112 (66)	0.80	2 (50.80)	NB	365	2680 (18)	170 (1172)	62	200 (1379)	48	—	—	—
Willow Creek	175C	175 (104)	0	1.06	3 (76.20)	NB	200	—	185 (1278)	65	—	—	—	57	500 deg hr
	175C80P	175 (104)	80 (47)	0.73	3 (76.20)	NB	200	—	186 (1279)	63	—	—	—	54	500 deg hr
	80C32P	80 (47)	32 (19)	1.61	3 (76.20)	NB	200	—	115 (793)	62	—	—	—	58	500 deg hr
Zintel Canyon	125CNA	125 (74)	0	1.50	2.5 (63.50)	NB	345	1510 (10)	85 (586)	56	10 (69)	40	14	—	—
	125CNA	125 (74)	0	1.50	2.5 (63.50)	B	345	1510 (10)	200 (1379)	54	10 (69)	40	14	65	—
	125CNA	125 (74)	0	1.50	2.5 (63.50)	P	345	1510 (10)	290 (1999)	56	0	55	14	—	—

Joint type: B = bedding concrete or mortar; NB = no bedding; and P = parent concrete.

Table 6



Sample quality control test

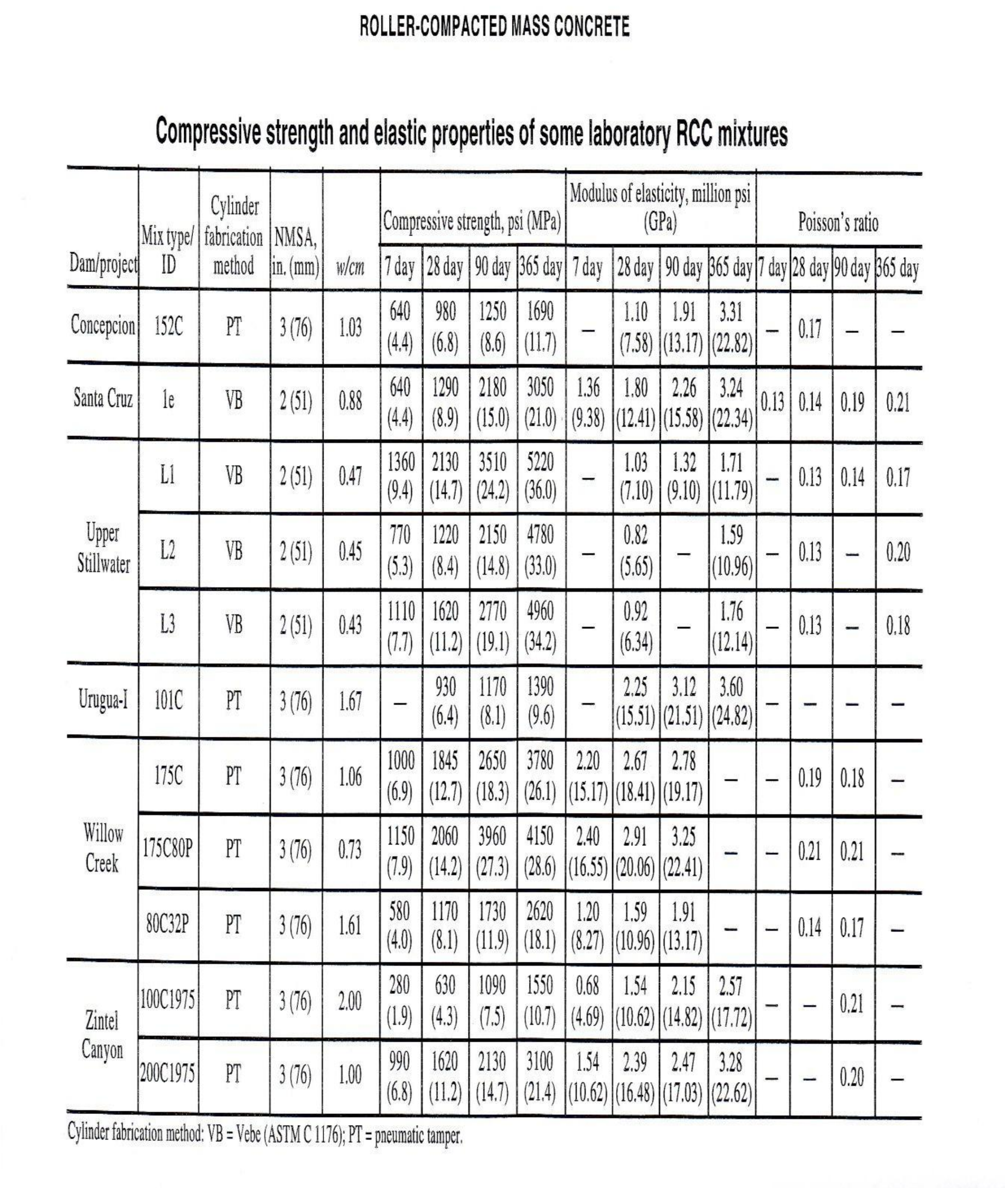
Material tested	Test procedure	Test standards*	Frequency†
Cement	Physical/chemical properties	ASTM C 150 or equivalent	Manufacturer's certification or prequalified
Pozzolan	Physical/chemical properties	ASTM C 618 or equivalent	Manufacturer's certification or prequalified
Admixtures	—	ASTM C 494 ASTM C 260	Manufacturer's certification
Aggregates	Specific gravity—absorption	ASTM C 127 ASTM C 128	1/month
	Grading	ASTM C 117 ASTM C 136	1/shift or 1/day
	Moisture content	ASTM C 566 ASTM C 70	Before each shift/or as required
	Flat/long particles	—	1/month or 10,000 yd^3 (7500 m^3)
	Plasticity of fines	—	1/month or 10,000 yd^3 (7500 m^3)
RCC	Consistency and density	ASTM C 1170	2/shift or as required
	In-place density	ASTM C 1040	1/hr or every 250 yd^3 (200 m^3)
	In-place moisture (double-probe, nuclear gage only)	ASTM C 1040	1/hr or every 250 yd^3 (200 m^3)
	Oven-dry moisture	ASTM C 566	1/shift or every 1000 yd^3 (750 m^3)
	Mixture proportions—RCC mix variability	ASTM C 172, C 1078, ASTM C 1079, special	1/week or every 5000 yd^3 (4000 m^3)
	Temperature	ASTM C 1064	1/2 hr or every 500 yd^3 (400 m^3)
	Compressive strength‡	ASTM C 1176 or tamper	1/day or every 5000 yd^3 (4000 m^3)
	Split tensile strength‡	ASTM C 496	1/day or every 5000 yd^3 (4000 m^3)
	Elastic modulus‡	ASTM C 469	1/day or every 5000 yd^3 (4000 m^3)

*Other appropriate industry standards may be used.

†Frequency shown is example typical of smaller projects and/or thorough agency testing. On larger projects and those with less stringent designs, less frequent testing may be appropriate.

‡Some projects used approach of relying on control during construction to achieve required quality, making few cylinders and taking cores afterward for verification of material properties in situ.

Table 7



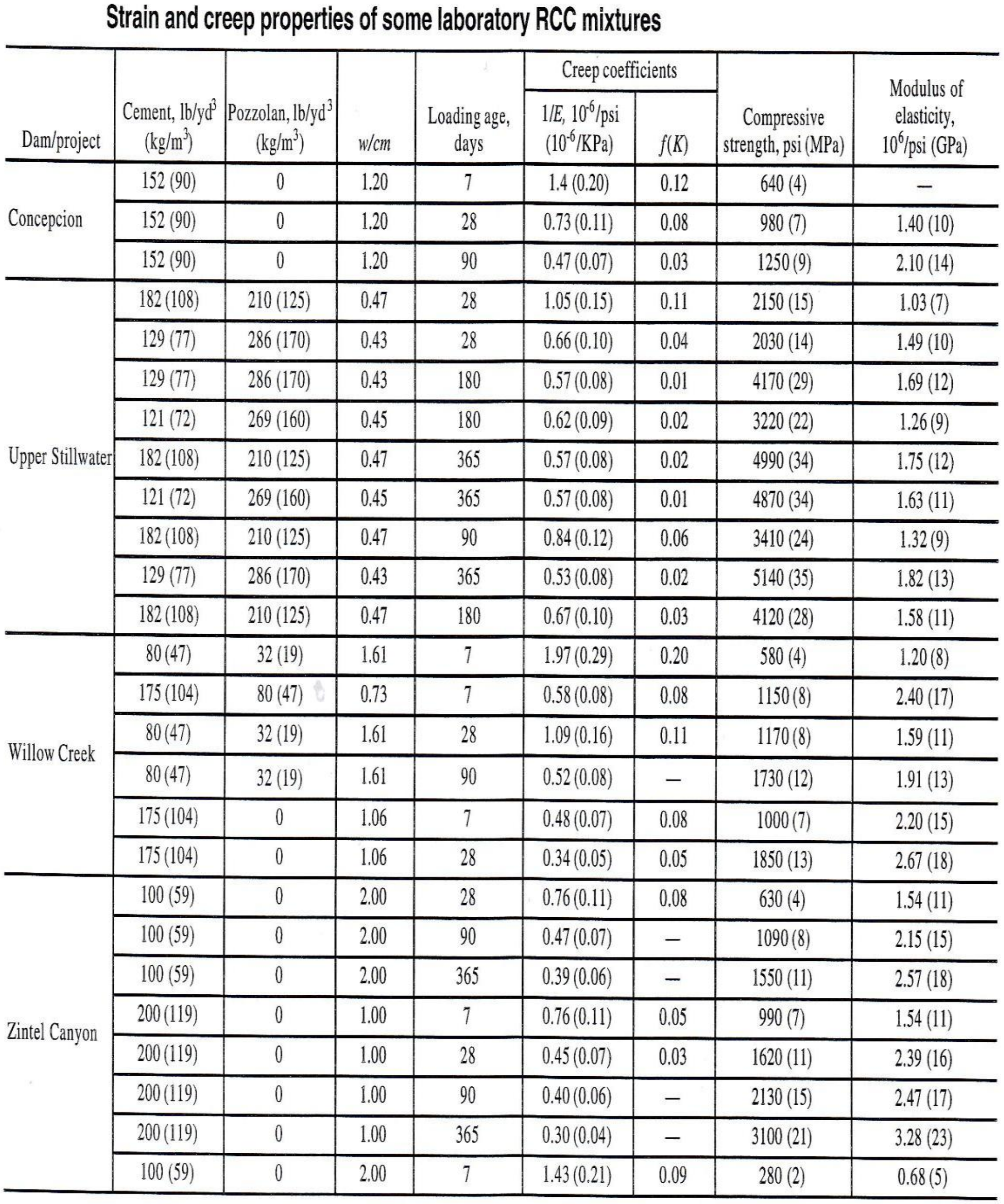
ROLLER-COMPACTED MASS CONCRETE

Compressive strength and elastic properties of some laboratory RCC mixtures

Dam/project	Mix type/ ID	Cylinder fabrication method	NMSA, in. (mm)	*w/cm*	Compressive strength, psi (MPa)				Modulus of elasticity, million psi (GPa)				Poisson's ratio			
					7 day	28 day	90 day	365 day	7 day	28 day	90 day	365 day	7 day	28 day	90 day	365 day
Concepcion	152C	PT	3 (76)	1.03	640 (4.4)	980 (6.8)	1250 (8.6)	1690 (11.7)	—	1.10 (7.58)	1.91 (13.17)	3.31 (22.82)	—	0.17	—	—
Santa Cruz	1e	VB	2 (51)	0.88	640 (4.4)	1290 (8.9)	2180 (15.0)	3050 (21.0)	1.36 (9.38)	1.80 (12.41)	2.26 (15.58)	3.24 (22.34)	0.13	0.14	0.19	0.21
Upper Stillwater	L1	VB	2 (51)	0.47	1360 (9.4)	2130 (14.7)	3510 (24.2)	5220 (36.0)	—	1.03 (7.10)	1.32 (9.10)	1.71 (11.79)	—	0.13	0.14	0.17
	L2	VB	2 (51)	0.45	770 (5.3)	1220 (8.4)	2150 (14.8)	4780 (33.0)	—	0.82 (5.65)	—	1.59 (10.96)	—	0.13	—	0.20
	L3	VB	2 (51)	0.43	1110 (7.7)	1620 (11.2)	2770 (19.1)	4960 (34.2)	—	0.92 (6.34)	—	1.76 (12.14)	—	0.13	—	0.18
Urugua-I	101C	PT	3 (76)	1.67	—	930 (6.4)	1170 (8.1)	1390 (9.6)	—	2.25 (15.51)	3.12 (21.51)	3.60 (24.82)	—	—	—	—
Willow Creek	175C	PT	3 (76)	1.06	1000 (6.9)	1845 (12.7)	2650 (18.3)	3780 (26.1)	2.20 (15.17)	2.67 (18.41)	2.78 (19.17)	—	—	0.19	0.18	—
	175C80P	PT	3 (76)	0.73	1150 (7.9)	2060 (14.2)	3960 (27.3)	4150 (28.6)	2.40 (16.55)	2.91 (20.06)	3.25 (22.41)	—	—	0.21	0.21	—
	80C32P	PT	3 (76)	1.61	580 (4.0)	1170 (8.1)	1730 (11.9)	2620 (18.1)	1.20 (8.27)	1.59 (10.96)	1.91 (13.17)	—	—	0.14	0.17	—
Zintel Canyon	100C1975	PT	3 (76)	2.00	280 (1.9)	630 (4.3)	1090 (7.5)	1550 (10.7)	0.68 (4.69)	1.54 (10.62)	2.15 (14.82)	2.57 (17.72)	—	—	0.21	—
	200C1975	PT	3 (76)	1.00	990 (6.8)	1620 (11.2)	2130 (14.7)	3100 (21.4)	1.54 (10.62)	2.39 (16.48)	2.47 (17.03)	3.28 (22.62)	—	—	0.20	—

Cylinder fabrication method: VB = Vebe (ASTM C 1176); PT = pneumatic tamper.

Table 8



Strain and creep properties of some laboratory RCC mixtures

Dam/project	Cement, lb/yd^3 (kg/m^3)	Pozzolan, lb/yd^3 (kg/m^3)	w/cm	Loading age, days	Creep coefficients		Compressive strength, psi (MPa)	Modulus of elasticity, 10^6/psi (GPa)
					1/E, 10^{-6}/psi (10^{-6}/KPa)	f(K)		
Concepcion	152 (90)	0	1.20	7	1.4 (0.20)	0.12	640 (4)	—
	152 (90)	0	1.20	28	0.73 (0.11)	0.08	980 (7)	1.40 (10)
	152 (90)	0	1.20	90	0.47 (0.07)	0.03	1250 (9)	2.10 (14)
Upper Stillwater	182 (108)	210 (125)	0.47	28	1.05 (0.15)	0.11	2150 (15)	1.03 (7)
	129 (77)	286 (170)	0.43	28	0.66 (0.10)	0.04	2030 (14)	1.49 (10)
	129 (77)	286 (170)	0.43	180	0.57 (0.08)	0.01	4170 (29)	1.69 (12)
	121 (72)	269 (160)	0.45	180	0.62 (0.09)	0.02	3220 (22)	1.26 (9)
	182 (108)	210 (125)	0.47	365	0.57 (0.08)	0.02	4990 (34)	1.75 (12)
	121 (72)	269 (160)	0.45	365	0.57 (0.08)	0.01	4870 (34)	1.63 (11)
	182 (108)	210 (125)	0.47	90	0.84 (0.12)	0.06	3410 (24)	1.32 (9)
	129 (77)	286 (170)	0.43	365	0.53 (0.08)	0.02	5140 (35)	1.82 (13)
	182 (108)	210 (125)	0.47	180	0.67 (0.10)	0.03	4120 (28)	1.58 (11)
Willow Creek	80 (47)	32 (19)	1.61	7	1.97 (0.29)	0.20	580 (4)	1.20 (8)
	175 (104)	80 (47)	0.73	7	0.58 (0.08)	0.08	1150 (8)	2.40 (17)
	80 (47)	32 (19)	1.61	28	1.09 (0.16)	0.11	1170 (8)	1.59 (11)
	80 (47)	32 (19)	1.61	90	0.52 (0.08)	—	1730 (12)	1.91 (13)
	175 (104)	0	1.06	7	0.48 (0.07)	0.08	1000 (7)	2.20 (15)
	175 (104)	0	1.06	28	0.34 (0.05)	0.05	1850 (13)	2.67 (18)
Zintel Canyon	100 (59)	0	2.00	28	0.76 (0.11)	0.08	630 (4)	1.54 (11)
	100 (59)	0	2.00	90	0.47 (0.07)	—	1090 (8)	2.15 (15)
	100 (59)	0	2.00	365	0.39 (0.06)	—	1550 (11)	2.57 (18)
	200 (119)	0	1.00	7	0.76 (0.11)	0.05	990 (7)	1.54 (11)
	200 (119)	0	1.00	28	0.45 (0.07)	0.03	1620 (11)	2.39 (16)
	200 (119)	0	1.00	90	0.40 (0.06)	—	2130 (15)	2.47 (17)
	200 (119)	0	1.00	365	0.30 (0.04)	—	3100 (21)	3.28 (23)
	100 (59)	0	2.00	7	1.43 (0.21)	0.09	280 (2)	0.68 (5)

Table 9

Fig. 7- Vibratory compactor Used for RCC Paving In Dams

Fig. 8- Using Bulldozers to layering the concrete

Fig. 9- Constructing RCC Dams by using layer by layer concrete paving

Fig. 10- Construction of RCC dam in initial progress of works

Fig. 11- Layering suitable grout between the pavement layers

Fig. 12- RCC Dam after completion

Fig. 13- Adding additives to the surface of the concrete forms in dam in order to smooth surfaces

Fig. 14- Construction of RCC Dam in end levels of construction

Fig. 15- Testing the density of compacted concrete of the road

Fig. 16- Constructing the joints after layering

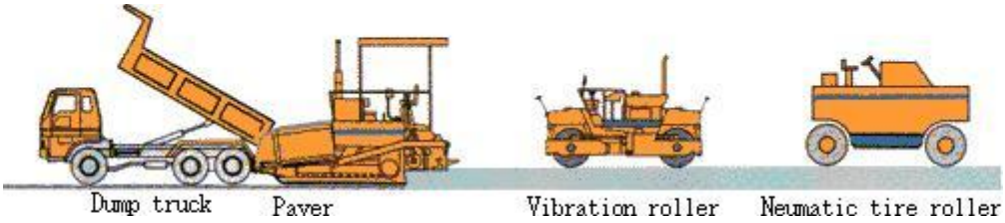


Fig 17-Machines and Equipments Used for RCC Paving

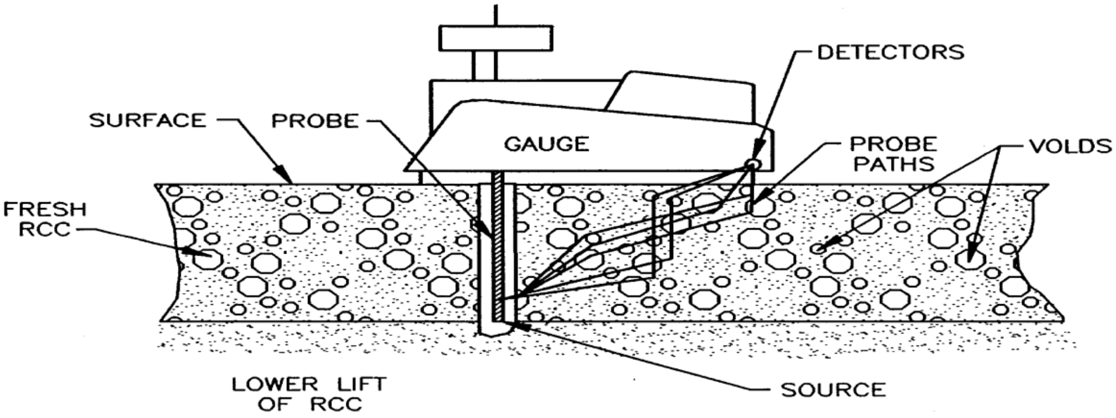


Fig 18- Single probe nuclear density gage.

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