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DEVELOPMENT OF HIGH INTEGRITY, MAXIMUM DURABILITY CONCRETE STRUCTURES FOR LLW DISPOSAL FACILITIES (U)

by

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DEVELOPMENT OF HIGH INTEGRITY, MAXIMUM DURABILITY CONCRETE STRUCTURES FOR LLW DISPOSAL FACILITIES

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ABSTRACT

A number of disposal facilities for Low-Level Radioactive Wastes have been planned for the Savannah River Site. Design has been completed for disposal vaults for several waste classifications and construction is nearly complete or well underway on some facilities. Specific design criteria varies somewhat for each waste classification. All disposal units have been designed as below-grade concrete vaults, although the majority will be above ground for many years before being encapsulated with earth at final closure. Some classes of vaults have a minimum required service life of 100 years. All vaults utilize a unique blend of cement, blast furnace slag and pozzolan. The design synthesizes the properties of the concrete mix with carefully planned design details and construction methodologies to (1) eliminate uncontrolled cracking; (2) minimize leakage potential; and (3) maximize durability. The first of these vaults will become operational in 1992.

PURPOSE

This paper describes the materials, methods and conceptual design of the concrete structures to enhance durability/service life and to meet specific performance objectives as derived from DOE Order 5820.2A and 5480.11 and proposed EPA Regulations 40 CFR 193 in the disposal of containerized wastes. This paper also discusses the results to date of the quality of completed construction. Also presented is a summary of methods presently being proposed for service life prediction.

BACKGROUND

Below-ground vaults are being planned as alternatives to shallow land disposal for low-level radioactive waste (LLW) at Savannah River Site (SRS).

Reinforced concrete is the predominant material used in the construction of the vaults. Other principal elements of the SRS disposal facilities but not included in the scope of this paper include flexible membrane liners for certain waste classifications, permeable drainage layers under and beside the vaults, and engineered clay caps over the vault complexes.

The design criteria for all structures requires that cracking be controlled to an absolute minimum to reduce leakage potential. The design criteria for certain of the LLW facilities also contains a requirement for 100-year minimum service life.

Construction Technology Laboratories, Inc. (CTL), Skokie, Illinois, were engaged to assist in the development and testing of the most suitable concrete mix to help meet these objectives. The principal CTL investigator was Mr. Steven H. Gebler.

In addition to the determination of proper mix materials it was recognized that design details and construction methodologies were of major importance. Engineering judgement further dictated that the design incorporate all cost-viable practical measures to enhance structural durability within the limits of available materials and usual construction practices. Construction of the initial vaults is by Bechtel Savannah River, Inc., under the direction of Mr. W. J. Harper.

LEAKAGE POTENTIAL

Properly cured ordinary Portland Cement concretes with water/cement ratios of 0.45 or lower have been determined by numerous investigators to have permeabilities of approximately 1×10^{-9} cm/sec where cracking is absent. This is 1 to 2 orders of magnitude better than clay liners or caps which are required by EPA acceptance criteria (Ref. 9) to have a permeability, i.e., hydraulic conductivity, no higher than 1×10^{-7} cm/sec. Thus, a .9144m thickness of ordinary concrete would have a permeability 100 times less than is practical to achieve in clay (Ref. 9).

Further, investigators for the Netherlands Delta Barrier Project (Refs. 1 and 2) found that slag-cement concrete had a permeability five (5) times less than for ordinary Portland Cement concrete.

Despite the hydraulic barrier posed by well constructed, uncracked concrete, it is not an acceptable substitute for a barrier of clay by EPA regulations because concrete usually cracks or contains other discontinuities. Even a very small crack that was not anticipated and provided with waterstop can change the hydraulic transport properties of a slab or wall by orders of magnitude.

SERVICE LIFE

Service life of a structure is defined as the period of time during which all functions intended in the design are fulfilled within a given environment.

The need for increased emphasis on durability of concrete structures during design is becoming increasingly obvious as evidenced by numerous articles by leading authorities in the design professions. With the need for long-term durability in such structures as those for containment of radioactive wastes it appears very probable that a minimum service life will increasingly become an integral part of the design requirement along with the customary strength requirements. Already, the regulations governing LLW disposal typically contain service life requirements of 100, 300, or 500 years for example.

Various methods of predicting service lives have been proposed or are under development. Most methods proposed in the United States have focused on either the durability of the concrete mix material alone or else with corrosion of steel reinforcing. None have been published dealing with the effects of such degradation mechanisms as volume change cracking or carbonation.

NUREG/CR-5542 (Ref. 3), recently published, is a critical review of mathematical models that predict concrete material properties over long time periods. It also discusses the recognized degradation mechanisms and concludes that "cracking is the one degradation process that most difficult to predict and can have the greatest impact on performance."

One approach to predicting service life receiving considerable attention is the Barrier code (Shuman, et al., 1989). However, it too neglects several degradation mechanisms.

In Europe, in addition to concern for material degradation, there has apparently been more interest in the functioning of the structure as a whole as indicated by Fagerlund (4), Somerville (5), and van Schaik (2).

Corrosion of steel reinforcement is recognized as a major issue among the various degradation mechanisms. One of the most important models for predicting the effect on service life of reinforcement corrosion is that proposed by Tuutti, 1982.

Service life expectancy studies are being performed on each SRS vault type utilizing the Barrier code. Results are expected in 1992. Pending the results of these studies and based on comparisons with the conclusions reported in References 1 and 2 service life predictions for the SRS vaults are expected to comfortably exceed 500 years.

MIXED DEVELOPMENT

Laboratory investigations, field trials and finally the construction of a full size test wall formed the basis of selection of the design mix.

Compressive strength, usually of primary importance in reinforced concrete design, was not a major concern. Structural design calculations were based on a minimum compressive strength of 2.7579 x 10^7 pascals at 91 days.

The design mix utilizes a unique blend of cement, ground granulated blast furnace slag (GGBS) and Flyash (pozzolan) in combination with low water cement ratio and superplasticizer to achieve a high workability, high durability, low permeability, low volume change concrete.

The design mix is in close agreement with the recommendations in References 6, 7, and 8 as well as being quite similar to the 200-year life mix adopted in References 1 and 2.

The design mix has a water cement ratio of 0.45 and contains 240.4kg of cementitious materials, i.e., cement content, per cubic yard of concrete as follows in Table I:

TABLE I

(a)	Portland Cement - Type II	-	56.7kg
(b)	GGBS	-	179.2kg
(c)	Flyash	-	61.2kg
	TOTAL		297.1kg

The mix utilizes locally available sand and 1.91cm maximum coarse aggregate and is precooled to 18.3°C maximum placement temperature with the use of liquid nitrogen. Air entrainment and superplasticizer (Type G) was used to enhance and prolong workability. Only chloride-free admixtures are permitted to minimize the potential for corrosion of steel reinforcement.

The concrete was supplied by an offsite batch plant over 16km distance from the construction site. This extended supply line was recognized as a significant difficulty in obtaining a satisfactory, uniform product with reliable and timely delivery considering potential for traffic tie ups and high temperature summertime conditions.

Slag was found to be beneficial in lowering heat evolution, reducing permeability and improving workability. Van Schaik (2) reports chloride permeability as reduced by a factor of 5 using a 30 percent cement/70 percent slag mix when compared with a 100 percent cement mix.

Flyash was found to be helpful in reducing shrinkage as well as improving the potential for early thermal cracking by lowering and delaying the peak hydration temperature and by slowing the post-peak cooling process.

The runner-up mix contained 30 percent cement and 70 percent slag with no flyash and exhibited very similar properties to the optimum mix which was chosen because of superior overall workability and cohesiveness.

CONCRETE PROPERTIES

The minimum required compressive strength of 27.5 x 10^6 pascals at 91 days was easily achieved, exceeded 48.3 x 10^6 pascals in all but one of the many tests performed during construction, varying from 41.4 x 10^6 pascals to 63.9 x 10^6 pascals. Compressive strengths at various ages are as follows in Table II:

TABLE II

Age-Days	Median Strength-Pascals	Strength Range-Pascals x 10^6
7	10.3 x 10^6	4.8 - 17.2
10	18.6 x 10^6	13.8 - 37.9
14	31.0 x 10^6	27.6 - 34.4
28	39.3 x 10^6	34.4 - 44.8
56	44.8 x 10^6	41.3 - 51.7
90	49.6 x 10^6	44.8 - 56.5

The peak hydration temperature was generally reached on the fifth day except during cold weather. The peak temperatures and times to peak are summarized in Table III.

TABLE III

Mean Ambient Temperature	Range of Peak Concrete Hydration Temperatures	Approximate No. of Days to Peak
7.2° - 10.0° C	18.0° - 23.8° C	11 - 13
10° - 12.7° C	23.8° - 29.4° C	8 - 10
12.7° - 18.3° C	29.4° - 35.0° C	7 - 8
18.3° - 23.8° C	35.0° - 37.7° C	5 - 7
23.8° - 29.4° C	37.7° - 40.5° C	5
7.2° - 10.0° C	40.5° - 43.3° C	5

After peaking, the concrete cooled to ambient temperature at a rate of approximately 3°F per day. This generally resulted in full dissipation of heat of hydration at a concrete age of approximately 10 to 12 days.

The insulation provided by plywood forms plus insulating blankets limited the temperature differential in most instances to less than -15°C and in every instance to less than -12.2°C.

By comparison, ordinary structural concrete would have a much higher peak hydration temperature, e.g., 51.7° - 65.6°C internally, at much earlier age, would cool at a much greater rate, would gain strength more rapidly for the first few days but have a lower strength after approximately 10 days. Potential for early thermal cracking is significantly increased with ordinary structural concrete when forms are stripped early, and curing water is applied causing rapid surface cooling.

DURABILITY

In planning for a structure of maximum durability, several factors are of paramount importance. The proper concrete mix is essential, of course. However, of equal or greater importance are such factors at structural design details, construction methods, and quality control at both the batch plant and the construction site.

A long-recognized major influence on concrete durability is its permeability. Low permeability is a pre-requisite for high durability concrete. Low permeability is in turn caused primarily by low water-cement ratio, proper cement type and content, proper compaction (vibration) and proper curing. Slag-cement concrete very similar to that developed for the SRS vaults was found to have a permeability to chloride penetration five (5) times less than ordinary Portland Cement concrete (Refs. 1 and 2). High durability concrete cannot be achieved with proper design and material selection alone. It is also imperative that construction be of high quality and fully recognized as such by the project criteria.

Other than high quality, low permeability concrete, and adequate cover for corrosion protection of steel reinforcement, the major concern is for the control of cracking.

Corrosion protection for reinforcement is provided by 6.4cm of cover with high quality, low permeability concrete. The concentration of chlorides in the SRS soils and environment is very small so there is no justification for epoxy coated reinforcement. Moreover, recent experience, particularly in Florida and mostly unpublished, indicates a noticeable increase in shrinkage cracking with the use of epoxy coated reinforcement. The maximum corrosion protection in such a mild chloride exposure is provided by the high pH, passivating zone provided naturally by high quality, low permeability concrete. For long-life structures exposed to the elements for several years before covering with earth, surfaces are coated to protect against carbonation attack.

In the design of the Eastern Scheldt Storm Surge Barrier (References 1 and 2) elimination of cracking was considered to be the greatest single factor in achieving a service life of 200 years in an aggressive, high chloride exposure. Walton, et al. (Ref. 3) indicates that a future NUREG publication will assess the impact of cracking on concrete durability.

CRACKING

The most important factors affecting cracking in concrete members 45.7cm or more in thickness, i.e., mass concrete, are the volume changes resulting from thermal and moisture changes. Other volume changes such as alkali-aggregate expansion are not considered of primary importance. Neither is flexural stress in properly reinforced members. References 7 and 8 discuss in detail the phenomena associated with cracking. Particular emphasis therein is placed on the need to reduce restraint to volume change and to control peak concrete temperatures.

Reference 7 states "The change in volume can be minimized by such measures as reducing cement content, replacing part of the cement with pozzolans, pre-cooling, post-cooling, and insulation to control the rate of heat absorbed or lost." It also stresses the need to reduce restraint to volume change tendencies as well as reducing the rate at which volume change takes place such as when cooling after hydration.

The need to minimize drying shrinkage has long been recognized as of major importance in controlling cracking. Major steps required to minimize drying shrinkage cracking include reducing water content to a minimum, an adequate system of contraction joints, proper reinforcement, moist curing and protection against rapid drying shock.

Volume change due to thermal changes, drying shrinkage or other cause would not result in cracking if there was no restraint. However, all concrete elements are restrained to some degree externally by the adjacent footings, walls, foundation soil or rock, etc. or internally by different parts of the element itself.

Internal restraint is caused by surface cooling while the interior temperature remains high. When this thermal difference exceeds 1.7°C, there is high likelihood of surface cracking. Once begun, these cracks propagate much more rapidly under subsequent temperature drops or drying shrinkage.

Major design or construction measures incorporated to minimize cracking in the vaults include the following:

1. Contraction control joints are provided at spacings no greater that 8.23m. Joints are detailed and constructed with great care to assure proper performance. At least 50 percent of reinforcing steel is interrupted at the joint. For best performance, the bars are terminated one (1) inch (± 1.3cm) from the joint. The joint section is further weakened by plastic embedments to promote a controlled crack.

2. Walls are poured full height in a single lift to minimize base restraint. Footings should be protected from drying shrinkage until each respective wall is constructed.

3. Reinforcing is uncoated in lieu of epoxy coated to enhance concrete bonding and lessen the tendency for shrinkage cracks to occur.

4. Form ties for walls include a threaded rod interior section which is left in place after forms are stripped to reduce the "stress riser" effects that are present when removable tapered ties are used creating open thruwall holes.

5. Wall forms are left in place for seven (7) days to enhance curing, provide necessary strength, and to protect against premature cooling or drying. Form removal is followed immediately by application of curing membrane to prevent rapid drying and to prolong the curing period.

6. Insulating blankets are provided over forms to minimize temperature differential within the concrete.

7. Temperature differentials from interior to exterior are monitored for at least 14 days by embedded thermocouples.

WATERSTOPS

Contraction control joints promote controlled cracks which are sealed by waterstops as are also construction joints. Waterstops for vaults with a required minimum service life of 100 years are High Density Polyethylene (HDPE). Waterstops for other vaults are of PVC.

RESULTS

Results to date have been excellent. All surfaces have been inspected at monthly intervals for presence of cracks and other defects. Foundation mats and floor slabs are completely free of uncontrolled cracks. Over 610m of walls have been constructed and fewer than ten (10) wall cracks (vertical) have been noted. Most of these occurred within 100cm of a control joint and were likely due to termination of reinforcing steel too far from the joint. Two (2) vertical cracks in walls occurred along rows of form ties and were probably due to base restraint caused by premature drying of the strip footings. Two (2) minor cracks were also noted in the 335m of wall strip footings.

All cracks will be grouted with flexible foam to assure their watertight integrity. A small number of surface discontinuities were noted in walls. These were generally .3m to 1.2m in length, and either horizontal or inclined up to 7.2°C. Upon further investigation, they were found to be very shallow, probably due to plastic settlement of the fresh concrete, and of no structural significance.

Very minor honeycombing was noted and surfaced "bugholes" were well within acceptable limits. The pre-cooling of the concrete during batching plus the use of extended life superplasticizer negated the lengthy (35-45 minute) travel time from batch plant to site. Thus, uniformity of delivered concrete was not a major problem.

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REFERENCES

1. T. Monnier and J. M. van Geest, "Durability Testing," Proceedings of the Delta Barrier Symposium, Rotterdam (1982)

2. H. van Schaik, "Durability and Corrosion," Proceedings of the Delta Barrier, Rotterdam (1982)

3. J. C. Walton, et al., "Models for Estimation of Service Life of Concrete Barriers in Low-Level Radioactive Waste Disposal," NUREG /CR-5542 (1990)

4. G. F. Fagerlund, "Service Life of Concrete Structures," Proceedings of Contemporary European Concrete Research, Stockholm (1981)

5. G. Somerville, "The Design Life of Concrete Structures," Paper to Institution of Structural Engineers, London (1986)

6. R. H. Denson, et al., "Recommendations to the NRC for Review Criteria for Alternative Methods of Low-Level Radioactive Waste Disposal, Below-Ground Vaults," NUREG-/CR-5041, Vol. 1 (1989)

7. "Effect of Restraint, Volume Change, and Reinforcement on Cracking of Mass Concrete," ACI 207.2R, ACI Materials Journal (May-June 1990)

8. "Control of Cracking in Concrete Structures," ACI 224R-80 (Rev. 1984), ACI Manual of Standard Practice

9. Requirements of Hazardous Waste Landfill Design, Construction and Closure, US EPA /625/4-89/022 (1989)

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