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High Performance Concrete for the Lacey V. Murrow Floating Bridge

Béton à hautes performances pour le pont flottant Lacey V. Murrow

Hochleistungsbeton für die Lacey-V.-Murrow-Schwimmbrücke

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SUMMARY

In early 1991, the Washington Department of Transportation began the design of twenty prestressed concrete pontoons for the replacement of the Lacey V. Murrow Bridge in Seattle, Washington. Designers of the pontoons were seeking watertight, durable concrete that would permit economical and high quality construction of these rather complex structures. The experience of the Owner and the Consulting Engineer indicated that these properties were achievable, but it would be necessary to develop specific material performance data and specifications. Research and development of the concrete mix designs, begun in mid-1991, allowed the beginning of construction in 1992.

RÉSUMÉ

Au début de 1991, le "Washington Department of Transportation" lança l'étude de 20 pontons en béton précontraints pour le remplacement du pont Lacey V. Murrow à Seattle. Il s'agissait alors de rechercher un type de béton à haute résistance et étanche à l'eau, dont la mise en oeuvre devait offrir une solution économique et de grande qualité pour ce genre de structure portante fort complexe. Si l'expérience du maître de l'ouvrage et de l'ingénieur-conseil tendait à confirmer la possibilité de satisfaire à ces exigences, il fallait encore établir un cahier des charges et des caractéristiques spécifiques pour les matériaux. Les recherches et le développement relatifs à la formulation de la composition du béton débuta vers la mi 1991, de sorte que la construction put démarrer en 1992.

ZUSAMMENFASSUNG

Anfang 1991 begann das "Washington Department of Transportation" mit dem Entwurf von 20 Spannbeton-Pontons als Ersatz für die Lacey-V.-Murrow-Brücke in Seattle. Für diese recht diffizilen Tragwerke wurde nach wasserdichtem, beständigem Beton gesucht, der eine wirtschaftliche und qualitativ hochstehende Bauausführung ermöglichen sollte. Nach Erfahrung von Eigentümer und beratendem Ingenieur waren diese Anforderungen erfüllbar, doch mussten spezifische Materialkennwerte und -pflichtenhefte erarbeitet werden. Die Entwicklung der Betonrezeptur begann Mitte 1991, so dass 1992 mit dem Bau angefangen werden konnte.

1. HISTORY OF FLOATING BRIDGES IN WASHINGTON

Four floating bridges have been designed and built in the State of Washington by WSDOT since 1940. The concrete in all of these has performed well, even under severe exposure conditions of saltwater, winds and waves, freezing and thawing, and abrasion. The state-of-the-art designs used for the two most recent floating bridges, I-90 and the LVM replacement, require high strength, low shrinkage, and low permeability concrete. These designs also include thin, deep bulkheads and walls, which are heavily reinforced and contain post-tensioning ducts. Thus, the demands for high performance concrete have increased.

The LVM replacement pontoons were necessitated by the sinking of the original 50-year old bridge in November, 1990. Design of the new pontoons with prestressed high performance concrete was to limit or prevent cracking and leakage. Corrosion of reinforcement and prestressed steel in the fresh water of Lake Washington, site of the LVM bridge, is not considered a severe threat to structural integrity, but can occur over a long period of time with normal concrete.

2. CONSTRUCTION DEMANDS ON CONCRETE

The greatest concern by WSDOT for water tightness and durability was in the outer shell of the pontoon which is directly exposed to water. This area of the pontoon requires fresh concrete properties be given special attention. Flowable concrete, with sufficient cohesiveness to prevent segregation, is needed for placing concrete in the heavily reinforced, deep walls. Workable concrete, with moderate slump and normal setting time, is required for flatwork in the slabs. While those characteristics are not necessarily incompatible, they do depend on a great deal of flexibility in the concrete mix.

Contractor incentive for early completion, and WSDOT's desire to reopen this vital link on the heavily-travelled Interstate 90 commuter corridor, dictated fast-track construction conditions. The design encouraged large, continuous concrete placements in walls and slabs in order to minimize construction joints. These factors combined to impose requirements for consistent and controllable concrete quality. Low slump loss and effective slump control were critical elements for consideration in the concrete mix design and development.

3. MIX DESIGN REQUIREMENTS

Parameters for the recommended final mix design, concrete placement, and curing were selected after all results from a mockup test were analyzed. A certain amount of flexibility was allowed in the mix design so the contractor could optimize the proportions to fit a particular supplier's materials. The table below compares the specified concrete properties to the contractor's final mix design and the WJE final test mix.

	WSDOT Specification	Contractor Mix Design	WJE Final Test Mix Design
Portland Cement, kg/m^3	371 min.	371	380
Silica Fume, kg/m^3	30 - 42	30	38
Fly Ash, kg/m^3	59 min.	59	83
Water-cementitious ratio*	0.33 max.	0.33	0.33
Max. Slump, in.	225	225	210

* Cementitious material includes cement, silica fume, and fly ash

Table 1 Comparison of LVM Mix Designs and Specifications

A maximum coarse aggregate size of 12 mm was specified because of tight clearances in the walls and knowledge obtained from the performance of other high strength concrete in the Seattle area and the LVM trial mixes. A coarse, WSDOT Class 1 sand was specified because it has exhibited the best workability and highest strength in previous applications of high strength concrete.

Trial mix tests and previous experience had shown that a combination of admixtures produced optimum workability, strength, slump retention, and density. It is well known that silica fume concrete requires the use of a high range water reducer because of the extra water demand created by the extreme fineness of the admixture. The introduction of a normal range, retarding water reducer at the batch plant, with a portion or all of the high range water reducer, is standard practice in the Seattle area for high strength concrete. The retarder aids in better slump retention and reduces the total amount of high range water reducer, thereby producing better and longer lasting workability. Thus, both types of water reducers were specified.

The decision to use non-air entrained concrete for the pontoons was somewhat controversial. There is not total agreement in the concrete industry that air entrainment is essential in high strength concrete with a very low water-cement ratio. It has been demonstrated in previous research [2] that some entrained air is necessary to produce concrete that is resistant to the severe exposure of standard rapid freeze-thaw tests. However, successful experience in the mild Seattle climate, and even the severe Alaska climates, with non-air-entrained high strength concrete in piling, pier decks, and other bridge pontoons, supports the argument for omitting entrained air. The air-entraining agent, besides adding a difficult control element in high performance concrete, produces stickiness that impairs workability and placeability.

4. MIX PERFORMANCE REQUIREMENTS

The ability of concrete to be watertight can be measured, to a large degree, by its permeability and shrinkage. The rapid chloride permeability test, AASHTO T-277, is now commonly used to measure the resistance of concrete to intrusion of chlorides. Low values of permeability are considered to be consistent with water tightness. The specifications required rapid chloride permeability tests for acceptance of the mix design, and also as a quality assurance test during construction.

Thermal shrinkage was a concern with this type of structure. Thermal shrinkage of newly-cast concrete against previously-cast concrete can cause cracking in thick sections, as the new concrete hardens and cools and is restrained by the older, cooler concrete. This could happen, for instance, at the base of a wall cast on top of the base slab. Temperature rise of the LVM mix was minimized by the use of Type II cement, lowest possible cement content, addition of pozzolans, and the cooling of formwork after concrete placement. The temperature of concrete in walls was required to be monitored at selected times during construction to assure that thermal shock would not occur as forms were stripped. The mild winter temperatures in Seattle assist in minimizing differential thermal shrinkage.

The specifications required that external vibration be used on the wall forms to assist in consolidation. This followed from results of the test mockup and previous experience in constructing other pontoon walls, with double layers of vertical and horizontal reinforcement, post-tensioning ducts, and blockouts for openings in the walls. It is known that wood formwork is not conducive to good transmission of form vibration into the concrete, but a constraint to use only steel forms was judged to be too costly. Other conditions for the pontoon construction, such as minimal use of vertical construction joints, and possible multiple construction sites, meant that economical reuse of more costly steel forms might not be possible. However, it was required that the design of the formwork produce the stiffness needed to transmit vibration and remain serviceable throughout construction.

Provisions in the specifications were made to allow the contractor to drop concrete more than 1525 mm in the walls, if it could be shown that segregation did not occur, and that dense, impermeable concrete could be produced. This economic and performance benefit was, of course, one of the objectives of WJE in designing the high performance LVM concrete mix. The 1525 mm restriction in the WSDOT Standard Specifications could be waived as a result of a more cohesive concrete and the use of external form vibration.

Water tightness of the pontoons was a primary concern of the designers when specifying construction joint locations and details. The combined experience of WJE and WSDOT signified that, when leaks occur, they usually are found at construction joints and around wall penetrations. Bond across construction joints by chemical adhesion and mechanical interlock was enhanced by requiring roughening of the hardened surfaces. The contractor achieved this by performing a high-pressure water blast of the surfaces before the concrete was too strong to resist removal of laitance, while still allowing roughening without weakening aggregate bond. Thorough compaction of concrete against the joints was emphasized, with a 600 mm height restriction of the bottom lift of wall placements. Specifications further limited the number of vertical and horizontal joints to reduce sources of potential leakage.

The LVM mix design produced concrete that yielded little or no bleed water to the surface. As a result, the top surface of flatwork, such as slabs, was difficult to finish to a closed surface, free of honeycombing. The lack of bleed water may result in plastic shrinkage cracking: the short, discontinuous cracks that occur before final set of the concrete slab. Both of these problems were mitigated by fog-spraying the surface immediately after the concrete was placed and screeded, and just before finishing and application of curing. It is imperative that a true, fine mist spray be used. The special provisions for this project permitted the fog spray, but did not require it.

Positive, moist curing of exposed concrete surfaces was stressed in the specifications in order to minimize permeability and cracking. Ponding of the slabs and top surfaces of the formed concrete was required. The outside wall forms were left in place for a minimum of 14 days after initial set had occurred. After inside form removal, walls were sprayed with curing compound. The very low water-cement ratio concrete used in the pontoons must be cured with water to avoid desiccation and disruption of the integrity of the internal cement paste.

5. CONCRETE CONSISTENCY AND PLACEMENT

The general arrangement at the time of placing concrete in the first pontoon in the Seattle graving dock is shown in Fig. 1. Previous experience in the construction of an oil exploration platform built in Japan made it clear that placement of concrete in the typical deep walls was best done by using modified tremie systems. The tremie is lowered into the top of the wall and slowly withdrawn as the level of concrete rises. The upper lifts of concrete can be easily placed from the top of the wall without the tremie. The outer layer of vertical reinforcement is spaced to allow room for the tremie insertion. The LVM bridge contractor followed this suggestion and used a modified structural tubing attached to the concrete pump hose to place concrete in all the remaining walls and bulkheads (see Figs. 2 and 3).

The lower lifts of concrete were placed with a slump of 175 to 240 mm, with best results at 225 mm or above. As the concrete level neared the top of the wall forms, the slump was decreased to 100 to 125 mm. Finally, a slump of 75 mm was used on the top lift. The lower slump eliminated practically all bleed water and laitance at the top and allowed earlier joint preparation by water blasting. The latter was possible because of less retardation of concrete set. Lower slump was achieved by substantially reducing the amount of high range water reducer. As the pontoon construction progressed, slump was easily adjusted and controlled to fit the placement needs; lower slumps were used where high slump was not required.

6. COMPRESSIVE STRENGTH TEST RESULTS

As expected, the achievement of the design compressive strength of was never a problem during construction. The average compressive strength of all tests at 28 days was 72 MPa. No attempt was made to establish strength beyond 28 days, but that determination was made during the LVM Mix Design Development testing. Those tests showed a strength gain of about 15 percent from 28 to 90 days, for mixes similar to the final LVM mix. Thus, the 90 day strength for the pontoon construction is estimated to average 83 MPa.

7. RAPID CHLORIDE PERMEABILITY TEST RESULTS

The AASHTO T-277 test for Rapid Chloride Permeability was conducted at a frequency of about one test for each 2620 cubic meters of concrete placed. The results were informational only. They were not used as a basis for acceptance of concrete. At least two specimens from each sampling were tested at 28 days and, in many cases, other specimens from the same sample were tested at 56 days and 90 days, and a few at 7 or 14 days. A statistical summary of the tests is shown in the following table:

STATISTIC	28d	56d	90d
No. of Tests	109	51	22
Average Perm, Coulombs	1327	785	577
Standard Deviation	523	230	135
Range of Results	517 - 2784	368 - 1608	310 - 804

Table 2 Statistical Summary of Rapid Chloride Permeability Test Results

It can be seen that the permeability is well below the targeted maximum of 1000 coulombs at 56 days, thought to represent concrete with excellent resistance to chloride intrusion. There is significant reduction of permeability with age, as can be seen in the table. Reference 3 in the Appendix describes some extensive research on permeability of various concretes, some containing silica fume and fly ash. It can be seen from Table 1 in the reference that rapid permeability results were 570, 340, and 168 coulombs at 28, 90, and 365 days, respectively. Those values are slightly lower than those on this project, but are about the same as those obtained during the mix development phase.

8. SUMMARY AND RECOMMENDATIONS

The risk of proceeding into construction with concrete specifications that had no history of previous performance on WSDOT projects was minimized by undertaking a rather extensive development program. Pre-construction testing further reduced the potential for major problems. However, those efforts would have been wasted had the contractor and concrete supplier not been willing to extend themselves and make these different approaches work. The successful conclusion of the pontoon construction was greatly assisted by the cooperative efforts of WSDOT, the contractor, the concrete supplier and WJE. Post-construction input from all of these parties has confirmed that the high performance concrete, external vibration, and other mitigative construction methods, were proven to be necessary.

9. REFERENCES

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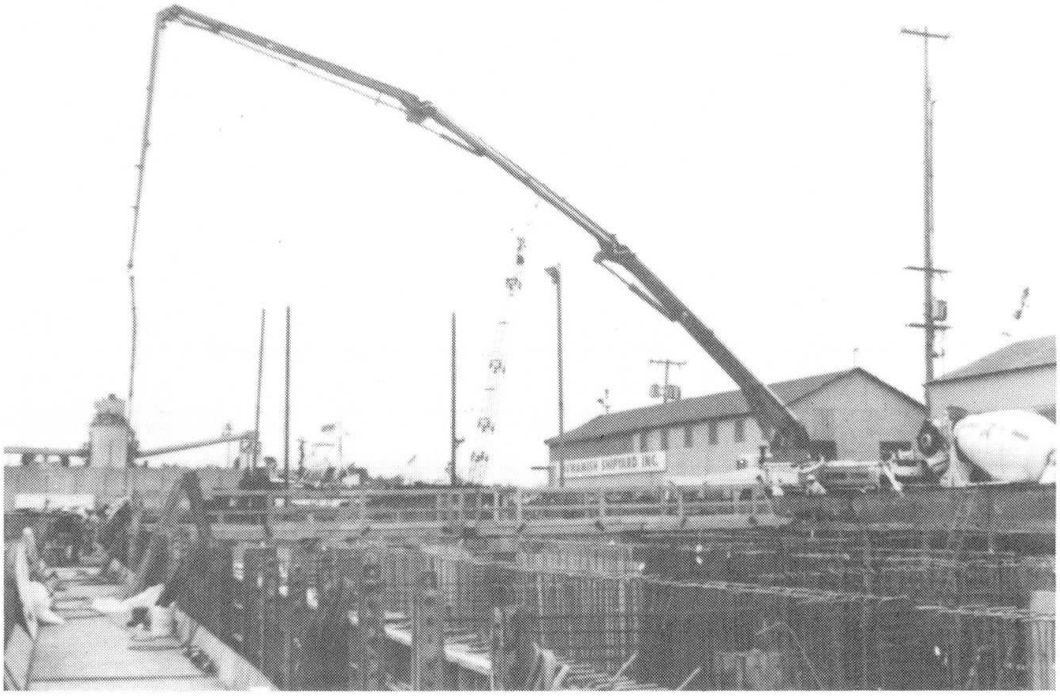

Fig. 1 - Seattle graving dock layout for concrete placement.

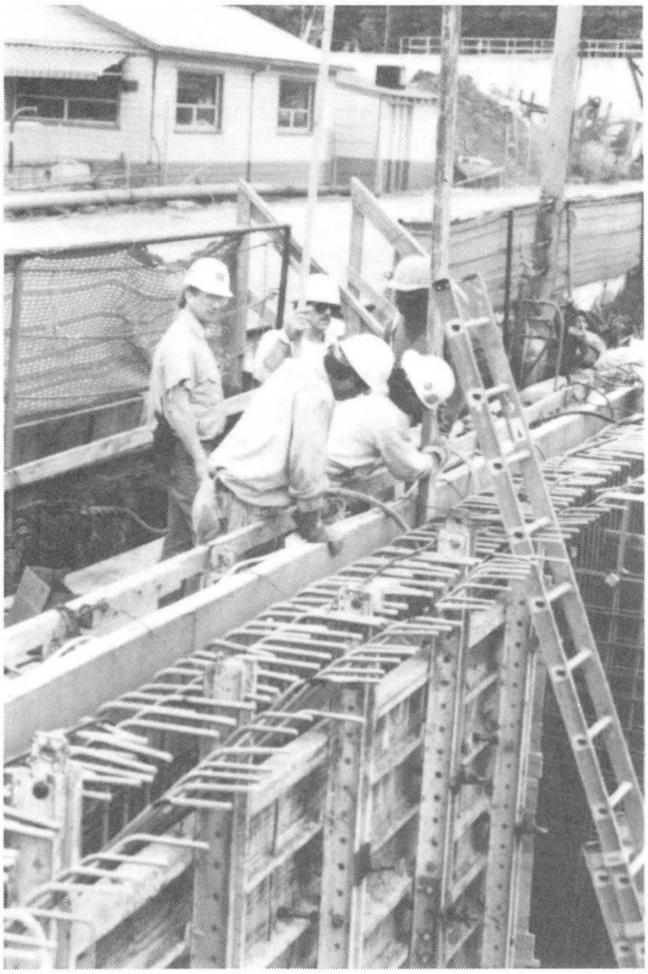

Fig. 2 - Closeup of tremie tube inserted in wall form next to form surface. Note internal vibrator on right.