INCIDENT REPORT
Fifteenth Lift Concrete Voids

I. SUMMARY

On October 20, 1978, Houston Lighting and Power Company (HL&P) notified the Nuclear Regulatory Commission (NRC) of a reportable deficiency under 10 CFR 50.55(e). This deficiency concerned the existence of concrete voids within Lift 15 behind the liner plate in the Unit I Reactor Containment Building exterior wall from El. 127'-0" to El. 138'-0". On November 20, 1978, an interim report regarding this deficiency was submitted to the NRC. Investigations have been conducted to determine the extent and location of all unacceptable areas. Repairs to restore the structure to the original level of safety have been completed. The repair methods were tested and the results analyzed prior to their implementation. This deficiency was caused by the compounded effects of inadequate planning for a large and complex pour, an unusually long pour time, longer than normal slick lines and concrete pump breakdowns. If left uncorrected, these voids could have compromised the structural integrity of the containment in that the containment as built could not have met its design load criteria.

II. DESCRIPTION OF INCIDENT

A. Identification

The Reactor Containment Building Unit I shell wall pour CS1-W15 showed honeycombing on the outer surface and visible voids between the liner plate and containment wall.

B. Extent

The voids were in a random pattern and existed throughout the circumference of the lift.

C. Date and Means of Obtaining Information

The voids were discovered at the final inspection of the pour by QC Inspectors and reported on NCR S-1219 on December 5, 1978.

D. Unusual Circumstances

This was an unusually long pour (over twenty hours), the pump broke down several times necessitating hand pumping and contributing to the time factor, the slick lines were longer than should have been used, and the lift was larger than the preceding fourteen. Structural members to support the polar crane rail protruded into the lift area.

E. Status of Construction

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Fourteen preceding successful lifts on the containment wall had been completed. Lift 15 would take the wall to the height of the polar crane rail.

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F. Procedures in Effect to Avoid Incident

The operating procedures provide for the stopping of the lift due to problems at any time by either Construction Supervision or Quality Control Supervision. This provision was not exercised.

III. CORRECTIVE ACTION

A. Upon discovery of the void condition, NCR number S-C1219 was initiated and assigned to Construction for resolution. At the same time this NCR was referred to the Quality Assurance member of the incident review committee. The Quality Representative called a meeting of the Incident Review Committee of B&R. At this meeting it was the opinion of the members that HL&P should be notified that a reportable incident existed. This action was taken without benefit of a safety analysis.

B. Complete Description of Immediate Corrective Actions Taken

1. Investigation to Determine the Extent and Location of Unacceptable Areas

The placement geometry (i.e., the extreme density of reinforcing steel, the configuration of embedded brackets, the prestressing tendon ducts and miscellaneous support steel) precluded the use of the currently available nondestructive testing techniques to adequately identify the unacceptable areas.

Exploratory drilling, sounding, and visual examination of holes using fiberoptics were the primary methods used to determine the extent and location of the unacceptable areas.

For the purpose of this investigation, unacceptable areas were defined as:

a. Areas in which the depth of the void between the liner and the concrete exceeded 1/8-inch. Sounding, drilling, and fiberoptic examination were used to determine such areas.

b. Areas in which underconsolidated concrete was evident. Drilling and fiberoptic examination were used to determine such areas.

A photograph of a typical area, including the grouting work platforms, is shown in Figure 1.

The placement geometry and history were evaluated and suspect areas, behind the brackets at which voids could be expected, were identified. To verify these assumptions, two brackets, at azimuth 260° and azimuth 290°, were selected at random and nominal 1-¼" Ø holes were drilled through the bracket. Two holes were also drilled through the liner beneath the bracket at azimuth 260°.

A model of a bracket with typical voids is shown in Figure 2 (the front face of the bracket is missing).

An Olympus fiberscope was used to determine the extent, location and surface characteristics of the voids.

Based on the above evaluation and an examination of the bracket geometry, the locations of holes to be drilled in each bracket were determined.

To identify the areas of non-contact between the liner and concrete, a one-foot grid (starting at the 0° azimuth) was laid out on the liner and the entire lift area (El. 127 to 138 excluding the area between grid line 139 & 220) sounded. All areas not indicating a steel/concrete contact were outlined on the grid.

Nominal 1-¼" Ø holes were drilled to determine the extent (depth) of these non-contact areas. A masonry bit was used to extend all holes drilled. If a void was evident behind the liner, it was examined with the fiberscope.

As anticipated, a large portion of the indicated "non-contact" area was the result of normal concrete settlement and shrinkage. The depth of these voids was minimal (less than 1/8").

Conclusions based upon this investigation were that there were primarily three situations requiring grout injection behind the liner. These were (1) areas previously identified on NCR S-C1219 visible at the top of the lift (i.e., areas at 5°, 20°, 50° and 305°), (2) areas generally beneath the brackets and (3) areas beneath the horizontal 8-inch channel stiffener in which sounding indicated "non-contact". Also, it was concluded that areas behind the 3/8" liner plate which sounded solid were solid, and that soundings did not necessarily imply a void.

Areas indicating "non-contact" where weldments were made such as the work platforms at each bracket and the continuous platform welded at the "J" line (El. 129'-0") were not voids as verified by drilling. Other isolated areas not previously mentioned resulted from normal shrinkage and settlement, or were within acceptable limits.

The entire exterior of Lift 15 was visually examined and any areas in which underconsolidated concrete was evident were investigated utilizing a series of nominal 3/4" Ø holes drilled approximately 14" deep and cleaned of any residue left from drilling. The holes encompassed the suspect area plus a minimum of one foot in each direction. The holes were examined with the fiberscope to determine the nature and extent of the unacceptable areas.

2. Material Qualifications

The material selected to fill the voids behind the liner was a commercial high-strength, highly fluid, non-shrink portland cement-based grout.

A program to verify the suitability of this material for its intended use consisted of:

a. Laboratory tests to verify its compliance to the CRD requirement (C-588-76), Corp of Engineers Specification, for non-shrink grout, compressive strength and modulus of elasticity, and

b. Field tests to investigate (1) flow and bond characteristics over simulated surface, (2) bond/shear characteristics of concrete/grout interfaces at various angles, and (3) Nelson stud/grout modes of failure, versus concrete failure.

All tests confirmed the suitability of the grout for the intended use.

3. Calculations

A calculation was performed to thoroughly examine, re-analyze and re-design the Containment Shell Lift #15 for the grout repair.

To aid the analysis of concrete/grout interface, four separate tests were conducted, as described below:

a. To simulate the actual concrete/grout interface, grout was poured over a concrete block with a rough surface at 60° to the horizontal. Drilled cores were studied for compressive strength.

b. Concrete/grout interface cylinders were studied to determine the effect of the slope of interface angle on the compressive strength.

c. Concrete/grout blocks were tested in direct shear to obtain a bond shear value for use in design.

d. Studs embedded in a grout block were tested in direct shear to obtain an allowable shear carrying capacity of the studs.

An example of a typical test core from test a above, is contained in Figure 3.

Based on tests a and b, a compressive strength of fc'=4000 psi was established conservatively for the concrete/grout interface. Similarly, the direct shear value was established in test c and the shear value of studs embedded in grout in test d.

After establishing the design strengths of the concrete/grout interface, the following major steps in design were re-evaluated for the new strengths:

a. Check the adequacy of the steel bracket anchorage system to transfer forces onto the concrete section.

b. Analyze interaction of the six components of forces in item a above.

c. Apply bracket forces on the Containment Shell to obtain the stress distribution in concrete by a Finite Element technique.

d. Re-design the concrete section for the forces obtained in c with the design strengths established on the basis of the test program mentioned earlier.

A systematic evaluation of the design showed that, based upon the test program, the grout repair would be adequate in transferring the forces from the bracket to the shell as well as reacting to these forces within the allowable stresses.

C. Long Term Corrective Actions Taken

1. Grouting

Masterflow 814 Grout, a material composed of hydraulic cements, was selected as the best available grout material for backfilling the voids because of its fluidity and pumpability and because it meets the requirements of CRD-C588-76, Corp of Engineers Specification for Non-Shrink Grout. This specification requires that non-shrink properties and strength be determined at the same fluidity and water content.

The grout does not bleed when mixed to high fluidity with a flow cone reading as high as 15 sec (flow cone, CRD-C79) at as-mixed temperatures as low as 35°F, provided the mix-water content is not in excess of that at which it was qualified at normal temperature (vicinity of 70°F).

High fluidity at the time of injection results in maximum penetration into surface voids for bond and into honeycomb for consolidation. Absence of bleeding means that bleed water will not collect at the top of voids or the

undersides of steel stiffeners and rebars to destroy contact and bond. The grout expands slightly after hardening to ensure permanent, tight contact with all surrounding concrete and steel surfaces. The 7 day and 28 day strength of the grout pumped into the voids averages 6250 and 7710 psi, respectively. This is in excess of that of the concrete in Lift 15 which tested in the range of 4990 to 5910 psi at 28 days and 6880 to 7690 psi at 90 days (f'_c= 5500 psi @ 90 days for the concrete).

The basic grouting equipment was a Chem-Grout unit consisting of two (2) vertical shaft mixers mounted over a progressive cavity pump (Moyno 2J6). Water was batched by gravity from a 50 gallon reservoir tank into a 25 gallon (approx.) batching tank over the mixers. For grouting the brackets, the above was mounted on a 12' x 30' platform erected on the top of the R.C. Bldg. wall over one of the buttresses. Grout hose, 1-¼" diameter, in 50' lengths as needed, transferred the grout to the point of injection. At the injection area, control was exercised by a ball valve followed by a pressure gage (0 to 30 psi) mounted on a skid that could be moved from bracket to bracket. A 10' length of 1" hose carried the grout from the skid to 3/4" i.d. inserts (with ball valves) screwed into nipples welded to the liner plate. A sonic velocity sensor (Polysonics Model UFM-P) was also attached to the pipe on the skid next to the pressure gage. Its attached meter showed whether grout was moving or not, in feet per second, and a built-in computer provided a indication of the volume being injected.

A photograph of the grouting operation is contained in Figure 4.

Because (1) the grouting procedure was one with which most concrete laborers and many engineers are not familiar and (2) the grouting of each bracket needs to be generally continuous from start to finish, three grout training sessions were held (one classroom and two mixing/pumping). See Figure 2, which is a picture of the mock-up prior to the training session.

Each bracket area was water-pressure tested on the day it was to be grouted to be sure that the concrete around the voids was saturated, to reveal the probable grout take, and to determine which holes were interconnected. This test also showed which holes might provide at least a venting capability, but were tight against the liner.

Observation of the external areas of the shell that had evidenced honeycomb and which had been chipped out prepara-

tory for repair, showed slight water leakage at three (3) areas and seepage at another.

Grout was mixed and pumped in accordance with the following procedure:

- Mixing water was precooled by floating ice in a 10,000 gallon tanker located at the base of the building and further cooled by shaved ice floating in both the reserve holding and batching tanks above the two mixers.

- Grout was mixed with the maximum water shown on certified test reports from the manufacturer. Ice from the 55-gallon drums was substituted for some of the mixing water (by weight) in order to achieve the lowest temperatures possible. The grout, as mixed, generally showed flow cone consistencies in the range of 15 to 20 seconds at temperatures of 40 to 50°F. The normal batch was 10 bags of Masterflow 814 grout which produced approximately 6.4 cu. ft. of fluid grout. Five bag batches were produced frequently for topping out.

- During or just prior to the start of mixing, free excess water was blown from the void areas with compressed air. Care was exercised to assure that air pressure would not build up behind the liner.

- The pump hopper and grout hose to the brackets, 20 feet below the platform and anywhere up to half way around the containment structure, were drained of water during the preparation of the first batch of grout. Grout was then pumped to waste into a 55-gal. drum at the bracket until all remaining water in the lines had been discharged and undiluted grout appeared.

- Grout connection was then made to the lowest open insert, as determined during the proceeding water pressure testing, and pumping started. As in the pressure testing, successively higher insert holes were shut off as full-consistency grout appeared, i.e., water-diluted grout and/or air bubbles were allowed to escape. As the area filled and the last interconnected hole closed, grout pressure was allowed to build up to 30 psi. Both the sonic flow meter and the pressure gage were watched for evidence of grout take. As long as a hole would accept a measurable amount of grout (pressure gage drop of 5 psi in about 15 sec. and/or a significant reading on the flow meter), the hole was repressured. Most areas "refused" at two or three pressure cycles, but a few were continued for as long as 10 minutes as water dripped from an open hole, which indicated continuing grout penetration into fine voids.

- Grout was next applied to peripheral holes where grout return had been minimal and to other holes not connected to the initial void system.

- Observation during grouting of the external repair areas that had previously shown some water leakage now revealed traces of grout. As traces of water and diluted grout appeared, a more consistent grout followed which plugged the flow path; thus, no external plugging was required.

- Both water and grout exited from the undersides of rebar, a not unusual indication of minor concrete settlement. It is a tribute to the flowability of the grout that under closing pressures the grout penetrated and consolidated generally all void areas in the vicinity of the brackets.

Twelve locations were selected at random for drilling of holes into the bracket areas to determine whether or not there were any ungrouted voids, and to inspect the quality of the grout in place and grout-concrete interface conditions. These holes were drilled until steel was encountered, but not deeper than 18".

Examination of each of these holes with the fiberscope revealed either solid grout, concrete or both. No voids were found, and interfaces between the grout and concrete were tight. Verification hole 281 B at bracket area 215° showed evidence that the grout had migrated through honeycomb.

D. Delineation of Testing Methods

To physically verify the adequacy of the Shell Lift #15 grout repair, a typical bracket was load tested. The bracket at azimuth 215° was chosen based upon the void pattern and accessibility for conducting the test.

The test bracket was loaded to a maximum vertical load of 375 tons, which is the load it will see during the Polar Crane Test lift of 520 tons. Only the vertical load and the corresponding moment were applied to the bracket. The radial and tangential force components are relatively small and therefore were not included as part of the test.

Based upon analysis, the displacements and strains were computed for the bracket test load of 375 tons, which was applied at a distance of 2'-8" from the liner face. These deformations were then compared with the test values as obtained from the strain gages and deflection gages. The maximum load of 375 tons was applied in increments and the deflection and strains measured at each increment, both during the loading and unloading cycle, to observe the load deflection behavior, and during

deformation recovery. The maximum observed strains of 284 in./in. compared well with predicted strain of 321 in./in. The observed vertical deflection at the bracket tip was 0.063μ/in. compared with a predicted deflection of 0.034μ/in. This difference was attributed to the sensitivity of the deflection gages to the temperature changes at the bracket location during the test time span, the ground vibrations at the site, and the general redundance of the deflection gage support structure.

For the critical strain gages, the recovery was around 90% and for the critical displacements, a recovery of 105% was obtained from test results. The deformation recovery of the critical gages and the load-deformation characteristics of the bracket structure show that it behaved elastically. It is therefore concluded that the grout method is adequate for the repair of voids in RCB 1 Containment Shell Lift 15.

E. Action to Prevent Recurrence

The Construction Supervisors and Engineers along with the Quality Control personnel have been subjected to a retraining program which identified the problems that contributed to the void problem. Such things as pump failure, excess time consumed in the lift were discussed and the proper procedures to be followed in such an event were enumerated. All personnel involved were made aware as to who has authority to take appropriate action and what constituted appropriate action. These training session have been completed.

IV. SAFETY ANALYSIS

An analysis to determine the safety implications of this incident was not conducted. The primary concern over these voids was the possibility of the failure of a polar crane bracket during lifting operations. Such a failure could not, by itself, have adversely affected the safety of operations since the polar crane is not used during power operations. There was a concern, however, that if left uncorrected, a polar crane bracket would not incur a total failure but that its deflections could induce structural damage that would not be readily visible. The possibilities of the second series failure from such cracks were determined to be too numerous and too speculative to analyze. Instead, the voids were repaired, as previously described.

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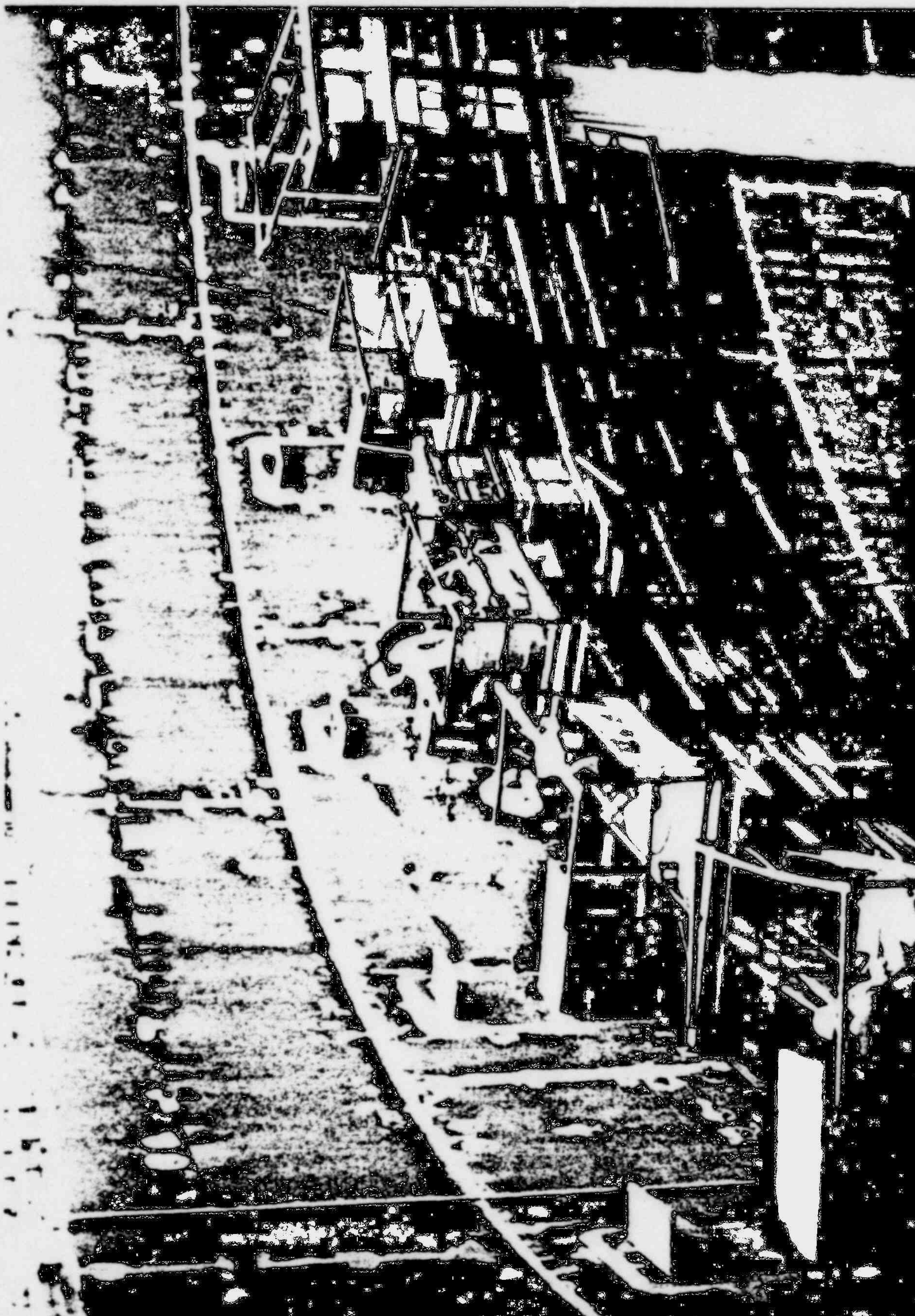
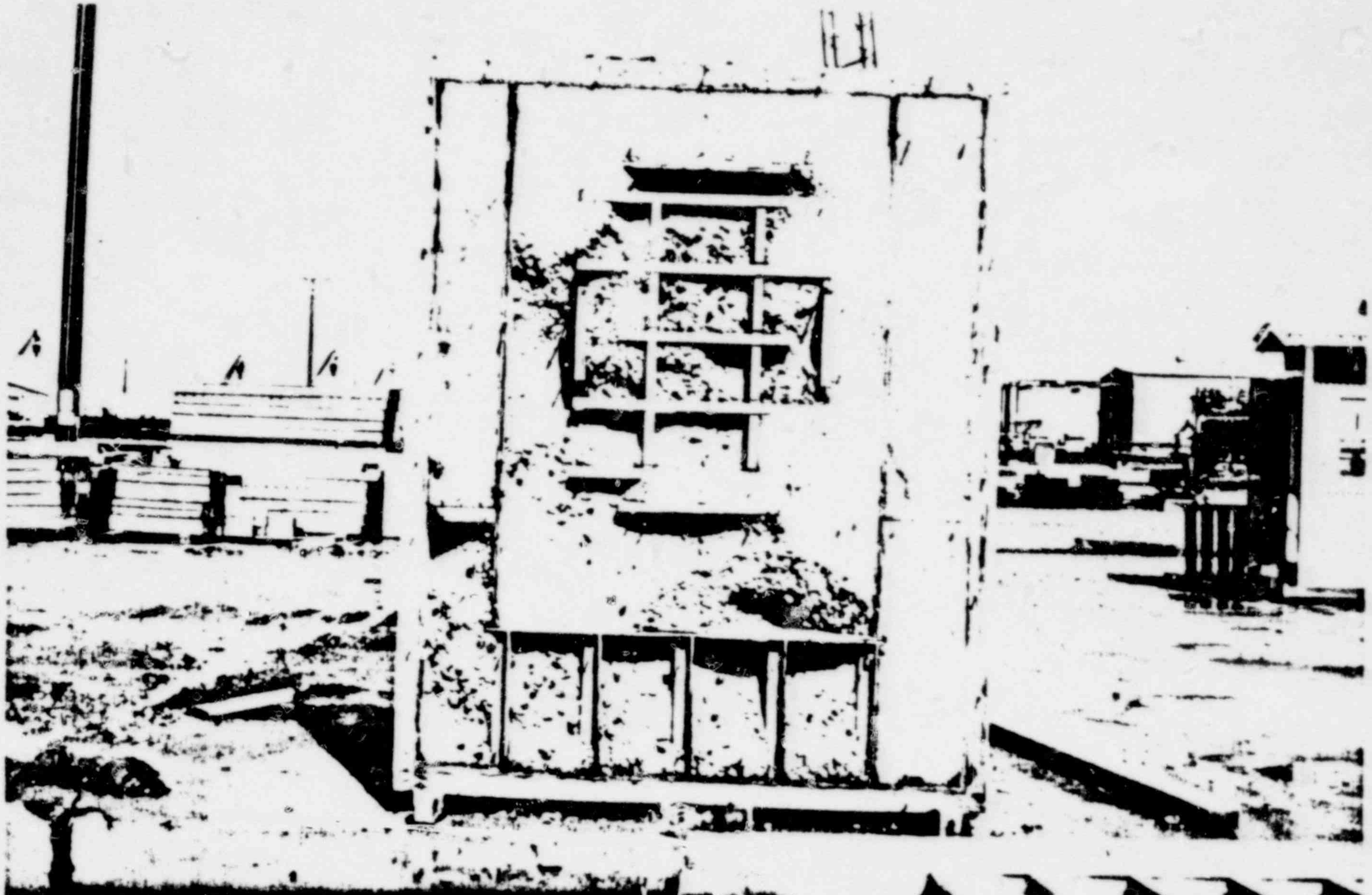


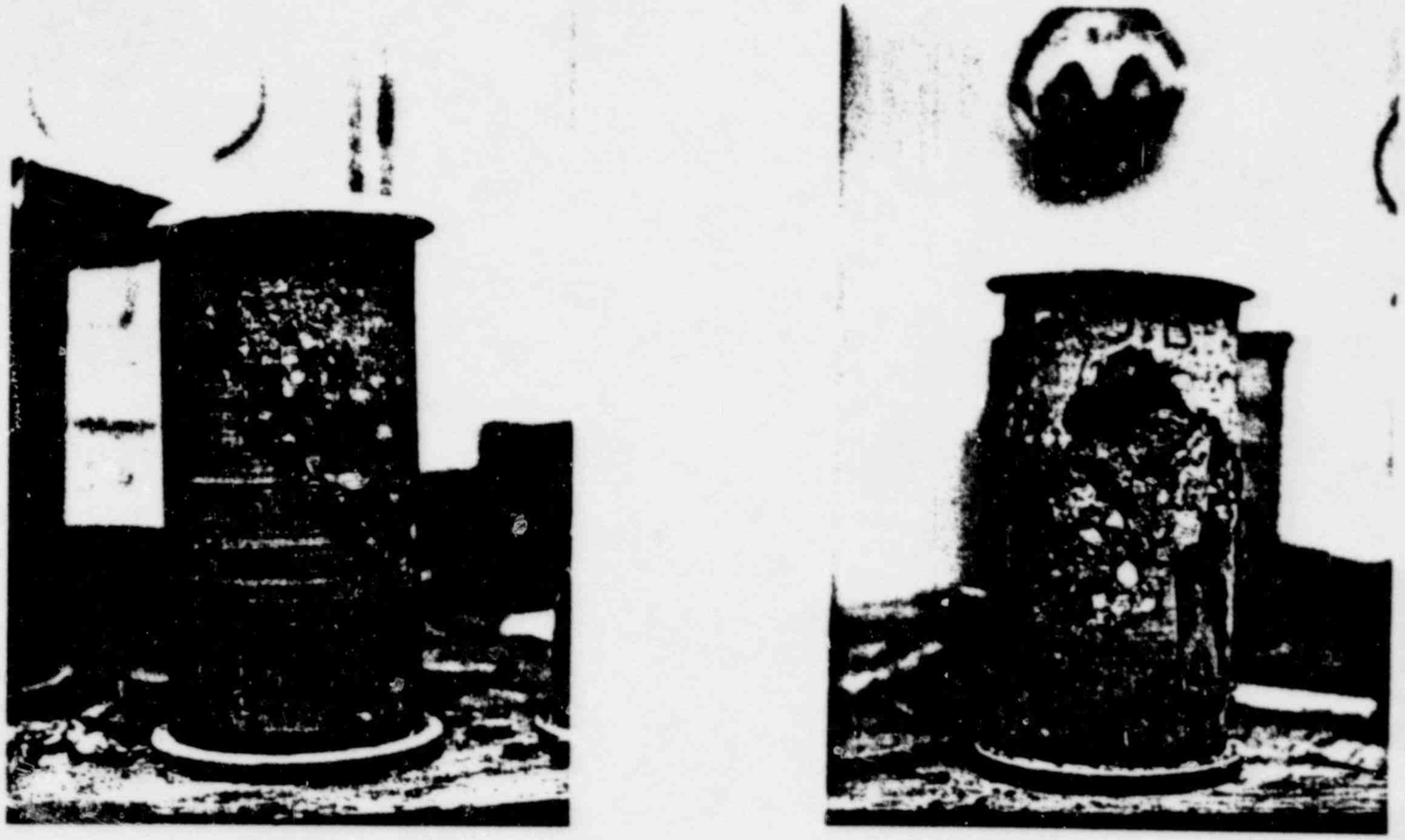
Typical Area, Grouting Work Platforms

Figure 1



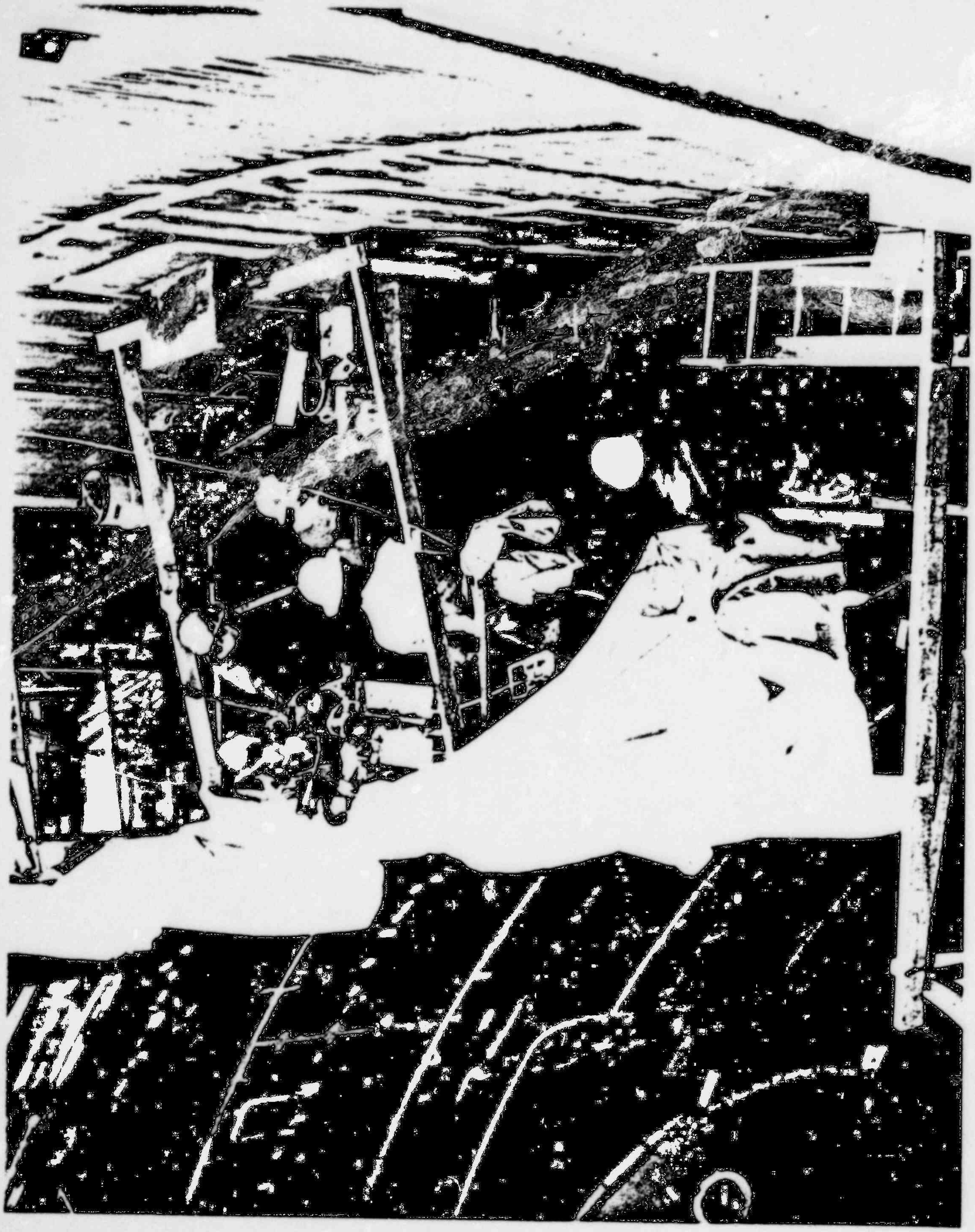
Bracket Model with Typical Voids

Figure 2



BEFORE TEST FOLLOWING TEST

Figure 3. An example of a typical test core (unconsolidated concrete and grout)



Grouting Operation In Progress

Figure 4