FINAL REPORT

INVESTIGATION AND REPAIR OF THE CONCRETE VOIDS
IN THE EXTERIOR SHELL WALL OF THE
STPEGS REACTOR CONTAINMENT BUILDINGS
1 AND 2

I. SUMMARY

On July 16, 1979, pursuant to 10CFR50.55(e), Houston Lighting & Power Company submitted to the Nuclear Regulatory Commission (NRC), Region IV, an interim report on the detection of concrete voids in the 8th lift of the Unit 1 Reactor Containment Building (RCB). On August 15, 1979, Houston Lighting & Power Company (HL&P) submitted a Second Interim Report on the Reportable Deficiency. At the time of this Second Interim Report, a significant amount of investigation was complete and recommendations for corrective action had been proposed. The repair work and full implementation of the recurrence control, however, had not been completed. At this time, the investigation and repair of the deficiencies for both Unit 1 (Lift 1 through 17) and Unit 2 (Lift 1 through 6) have been completed except for an area in Unit 2 as described below. The investigation and repair work on the fifteenth lift of the Unit 1 RCB had previously been completed and reported on June 5, 1979.

The concrete voids described herein were found to have occurred in areas beneath shell penetrations and/or beneath the 8 inch channel and plate stiffeners where additional reinforcing steel are located. The repairs to restore the concrete shell to its original structural integrity have been completed, except for an approximately 10 foot by 14 foot area in the Unit 2 RCB where the liner was inadvertently deformed. The repair methods used were thoroughly tested and analyzed prior to their use; and were, to a great extent, based upon the investigation and repair of the fifteenth lift in the Unit 1 Reactor Containment Building.

Subsequent to the discovery of the voids in Lift 8 of Unit 1, a Stop Work Notice was issued on all concrete pours. An investigation was conducted to determine the cause of the voids and as a result, a list of corrective action was defined that would preclude recurrence. This list was described in the Second Interim Report. Actions were taken to integrate these corrections into construction and inspection procedures; therefore, the Stop Work Notice was lifted.

During the investigation and analysis, it was determined that if left uncorrected, these voids could have compromised the structural integrity of the Containment shell in that the as-built configuration would not have met its design load and shielding criteria.

II. DESCRIPTION OF THE INCIDENT

a. Identification

During the investigation of the Lift 15 voids on the Unit 1 Containment Building, information was obtained from Site personnel which lead to the concern that voids might exist in Lift 8 of that same building.

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Soundings were begun and it was determined by drilling that voids did indeed exist. A program was established to identify all significant voids in the RCB exterior shell wall for both Units 1 and 2.

b. Extent

During the investigation of the extent of these voids, it was determined that where such voids did exist, they were located beneath penetrations and/or the 8 inch channel or plate stiffeners where additional steel was located. One special area in Unit 1 was investigated where a construction block-out had been located. The top of the block-out was suspected to have trapped voids during the placement because of the horizontal nature of the joint. One void at each top corner was found and repaired using the same procedures as the others.

Larger voids were found in areas of larger penetrations where concrete placement was more difficult due to the added congestion of reinforcing steel. Figures A and B represent the location and approximate volume of grout pumped into the voids for Units 1 and 2 respectively. Of the total number of holes drilled during this investigation in both Units, including all additional holes added for venting purposed, over 70% indicated that no void existed.

Unit 1: The largest void in terms of volume was located above the equipment hatch below an 8 inch plate stiffener. This void, however, did not extend through the shell wall. Voids were determined to have extended through the shell wall directly beneath the four main steam lines and two 58 inch diameter HVAC penetrations. These voids did not extend beyond 12 inches from the bottom of the penetration sleeve, with the majority not extending beyond 2 inches.

Unit 2: In general, voids determined in Unit 2 were not as large or deep as those found in Unit 1. One isolated area did vent to the outside of the Containment and was located below an electrical penetration near Azimuth 335$^{o}$ and Elev. 45'. All remaining voids were located at random positions beneath other penetrations and/or the 8 inch channel and plate stiffeners.

c. Means of Obtaining Information

For tracking purposes, the investigation was divided into the following phases:

- Phase 1 - Previous investigation and repair of Lift 15, Unit 1.
- Phase 2 - Lift 8, Unit 1.
- Phase 3 - Equipment Hatch, Personnel Hatch, and Main Steam and Feedwater Lines, Unit 1.

- o Phase 4 - Remaining Areas of Unit 1 where potential voids could exist.
- o Phase 5 - Unit 2 (Areas similar to Unit 1)

Phase 2 was dispositioned separately to permit closeout of the existing nonconformance report identified for Lift 8 and also to assist the construction schedule at this elevation. Phase 2 has been identified on a nonconformance report submitted on 9-12-79 with closeout including repair and verification on 11-13-79.

Phase 3, 4 and 5 have been identified on a nonconformance report submitted on 1-8-80 with final closeout including repair and verification on 2-7-80 with the exception of the areas at the liner deformation.

The work on these phases was identified in the nonconformance reporting system.

d. Status of Construction

At the time of the stop work order on June 22, 1979, concrete exterior wall placements had progressed through Lift 17 (Elev. +150') on Unit 1 and through Lift 6 (Elev. +47') on Unit 2.

e. Procedures in Effect to Avoid the Incident

Operating procedures were in effect that provided for preplacement planning and design engineering involvement in developing particular concreting methods to assist the placement. However, sufficient preplacement planning was not exercised and the procedures were determined to be inadequate.

III. CORRECTIVE ACTION

a. Investigation

Following completion of the investigation, as previously discussed in the Second Interim Report, the investigation was expanded to other areas of Unit 1 and similar areas in Unit 2.

The area identified in Phase 2 thru 5 were physically sounded by tapping to determine suspected voids behind the 3/8 inch liner membrane. A gap behind the 3/8 inch plate of as little as 0.001 inch to 0.002 inch will yield a hollow sound when the plate is tapped. Such spaces are caused by thermal shrinkage of the liner plate, concrete shrinkage and settlement, the attachment of temporary weldments, etc. and are not structurally significant. The presence of voids requiring grout (groutable voids) was then confirmed by drilling through the liner plate in places where potential voids could be expected such as under stiffeners and beneath penetrations where concentrated reinforcement was located. Other areas which sounded hollow, but where the lack of interferences made the occurrence of voids unlikely were also drilled. All such areas verified the absence of groutable voids.

Where the sounding method was uncertain, such as through the thickened collars and plates around the penetrations, holes were drilled through the plate beneath the 8 inch stiffeners and between the bottom gusset stiffeners of the penetration sleeve. Where any showed a void, successive holes were drilled to adequately define the void and until no void was found.

A similar pattern of holes were drilled through external collar plates around penetrations on the exterior of the containment shell to locate voids that might exist there and to provide vents for any voids that might extend from inside to outside. All such holes located in the area beneath penetrations were extended either until interference occurred or until they intersected a void on the opposite wall face.

All voids were pressure tested with water at controlled pressures to determine which holes were interconnected by voids behind the liner plate and also to see which vented to the outside. Interconnections were marked on the face of the liner and the optimum hole of an interconnected group was selected for the eventual grout injection point. This procedure, executed a day or so prior to grout, assured that the concrete would be saturated. It also served as a training or retraining program for personnel involved in the grouting operation in that the water was pumped through the same grout pump, grout hose and instrument skid (with pressure gauge) as was used for grouting. Headphone communication between the injection area and the pump was also used. On completion of testing in each area, the valves were opened to drain off the water and in some instances, the air line was connected to the top-most hole and remaining water was forced out the lowest hole by air pressure.

Water pressure behind the liner plate was held to 10 to 20 psi by limiting the pressure at the skid to 30 to 40 psi while the water was moving, the difference being pressure loss in the 20 to 30 feet of 3/4 inch hose due to elevation differences and connections between the skid and the liner. Whenever gauge pressures approached these values, water was shut off and the rate of pressure drop noted. If the drop was rapid, water was turned on again to determine interconnections or leaks to the outside. If the drop was slow, the test was terminated and the connection changed to another group of holes.

During testing of the Unit 2 RCB for void formations, inadvertent overpressurization occurred. This resulted in the "bulging" of a section of the steel liner. After relief of the overpressure, some residual deformation remained. This matter is being handled as a separate non-conformance.

b. Material Qualifications

The material selected to fill the voids behind the liner and beneath penetrations is Master Builders Masterflow 814 Prepackaged Commercial High Strength, Highly Fluid, Non-Shrink Portland Cement based grout which satisfies the requirements of CRD C588-76, Corps of Engineers Specification for Non-Shrink Grout. This grout does not bleed when mixed to a high fluidity with a flow cone reading as low as 15 seconds (flow cone, CRD C79) at as-mixed temperatures as low as 35$^{o}$F, provided the mix-water content is not in excess of that at which it was qualified at normal temperatures (the vicinity of 70$^{o}$F). High fluidity at the time of injection results in maximum penetration into the surface voids for bond and into honeycombed areas for consolidation. Absence of bleeding means that bleedwater will not collect at the top of the voids or at the undersides of the steel stiffeners and reinforcing steel to destroy contact and bond. The grout expands slightly after hardening to ensure permanent, tight contact with all surrounding concrete and steel surface.

Laboratory and field tests were performed previously for the Lift 15, Unit 1 RCB repair to verify the compressive strength, modulus of elasticity, flow and bond characteristics, and bond/shear characteristics of the concrete/grout interface. All tests have confirmed the suitability of this grout for the intended use.

c. Design Analysis

A calculation was performed to thoroughly examine and evaluate the Containment shell design, including the areas around the large and small penetrations. Based upon previous tests performed for the Lift 15, Unit 1 RCB repair, a compressive strength of $f'_c$ equal to 4,000 psi was established conservatively for the concrete/grout interface. The adequacy of the steel anchorage system of the penetrations to transfer forces into the concrete section was checked for the new strength. The design of the concrete shell sections, including the areas of stress concentrations around the penetrations, were re-evaluated for the new strength. A complete re-evaluation of the design showed that the grout repair would be adequate and the shell sections would be reacting within the allowable stresses under the design loads.

d. Repair

1. Grout Repair: The basic grouting equipment was a Chem-Grout unit which consisted of two (2) vertical shaft mixers mounted on a progressive cavity pump. Water was batched by gravity from a 50 gallon reservoir tank into a 25 gallon (approx.) batching tank located over the mixers. Grout hose, 1¼ inch diameter, in 50 foot 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 gauge mounted on a skid that could be moved from area to area. A 10 foot (longer if required) length of 1 inch hose carried the grout from the skid to 3/4 inch i.d. inserts (with ball valves) screwed into couplings welded to the liner plate. This is the same equipment that was used successfully in the repair of Lift 15, Unit 1.

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

- Mixing water was pre-cooled 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 material test reports from the manufacturer. Ice from 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$^{o}$F. The normal batch was 10 bags of Masterflow 814 grout which produced approximately 6 cubic feet of fluid grout. Five bag batches were produced frequently for topping out and where flow was slow.

- The pump hopper and grout hose were drained of water during the preparation of the first batch of grout. Grout was then pumped into a waste drum located at the liner connection 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 preceeding 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 20 to 30 psi. As long as a hole would accept a measurable amount of grout (pressure gauge drop of 5 psi in about 15 seconds and/or a noticeable vibration of the 1 inch hose at the liner insert), the hole was repressurized. 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.

- Grout was next applied to peripheral holes where grout return had been minimal.

2. Liner Repair: The investigation of the concrete behind the liner plate necessitated the drilling of nominal 1½ inch diameter holes. In addition to the holes drilled for investigative purposes, some holes had to be drilled to facilitate the injection and venting of grout into areas requiring repairs.

   The holes drilled in the liner plate have been repaired by using couplings made of approved ASTM materials. (ASME SA-105, ASME Section III, Division 2, Subsection CC for Couplings, Plugs and Fittings). These couplings have been machined to fit the holes and welded to the liner to meet the ASME requirements for leak tightness.

   A deformed liner section in the Unit 2 RCB is being repaired by removing the damaged section and replacing it with a new section. Grout repair in this area will then be performed using the same procedures mentioned above. The grout section will be keyed to the existing concrete. The repair will restore the liner and concrete section to its intended design condition.

e. Action to Prevent Recurrence

As a result of investigations referred to in the Second Interim Report for Lift 8, Unit 1 voids (on August 15, 1979), it was determined that recurrence could be prevented by providing for better accessibility to those areas of congestion where additional inspection and vibration is required, and by strengthening the construction and quality control procedures. Construction and inspection procedures and necessary engineering design documents have been revised to reflect the recommendations contained in Table 1 of the referenced Second Interim Report for the Lift 8 voids.

## IV. SAFETY ANALYSIS

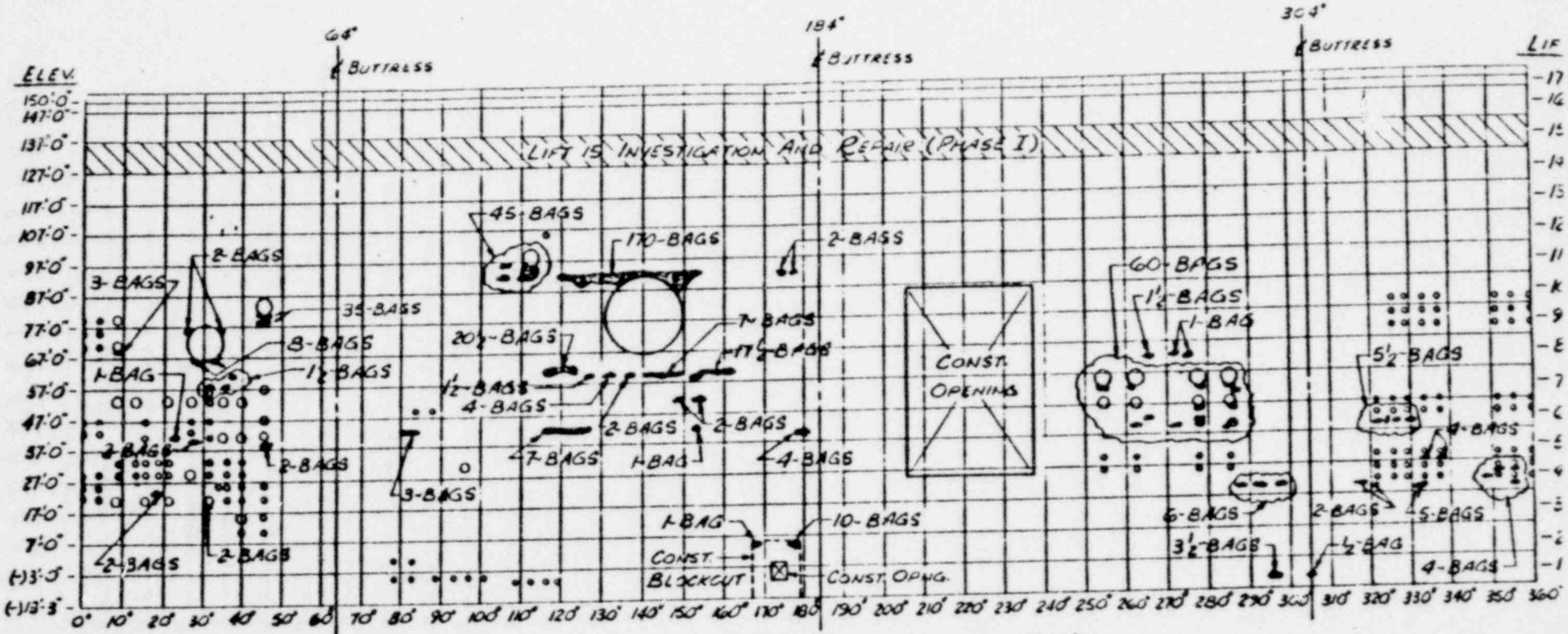
An analysis to determine the safety implications of this incident was conducted as follows:

- On June 18, 1979, the Incident Review Committee met and HL&P notified the NRC that the condition was reportable under the requirements of 10CFR50.55(e).

- The Committee determined that, if left uncorrected, these voids could have compromised the structural integrity of the RCB shell in that the as-built configuration would not have met its design load and shielding requirements.

- Areas where voids extended through the shell wall were evaluated for shielding requirements. The shielding adequacy was not compromised due to the fact that the voids were filled.

FIGURE - A



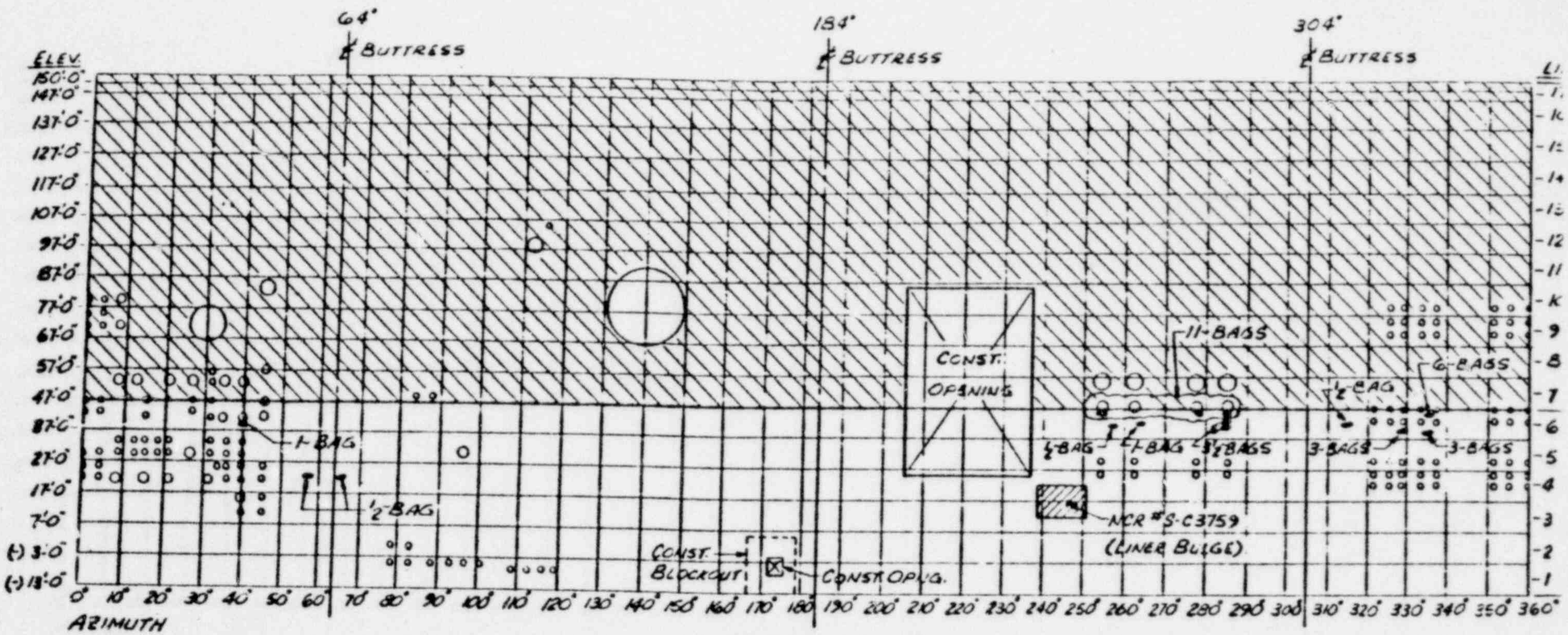

ELEVATION UNIT 1 (PHASE II III & IV)

NOTES:

1. ● DETERMINED VOIDS THAT WERE REPAIRED BY PRESSURE GROUTING.
2. TOTAL NUMBER OF BAGS = 449 = 10 CU. YDS.
3. TOTAL NUMBER OF HOLES DRILLED INSIDE THROUGH THE LINER PLATE = 767 WHICH INCLUDES APPROX. 222 USED TO LOCATE AND GROUT THE DETERMINED VOIDS.
4. TOTAL NUMBER OF HOLES DRILLED OUTSIDE TO HELP IDENTIFY AND PERMIT VENTING OF VOIDS LOCATED BENEATH PENETRATIONS = 31.

POOR ORIGINAL

FIGURE - B




ELEVATION UNIT 2 (PHASE V)

NOTES:

1. ● DETERMINED VOIDS THAT WERE REPAIRED BY PRESSURE GROUTING.
2. TOTAL NUMBER OF BAGS = 30 = 2/3 CU. YDS.
3. TOTAL NUMBER OF HOLES DRILLED INSIDE THROUGH THE LINER PLATE = 96 WHICH INCLUDES APPROX. 30 USED TO LOCATE AND GROUT THE DETERMINED VOIDS. (DOES NOT INCLUDE BULGE AREA.)
4. TOTAL NUMBER OF HOLES DRILLED OUTSIDE TO HELP IDENTIFY AND PERMIT VENTING OF VOIDS LOCATED BENEATH PENETRATIONS = 9.