DLA'S RESPONSES TO GARDNER AND ASSOCIATES' REPORT

General

The purpose of this letter report is to address several issues presented in a report prepared by W.S. Gardner and Associates (WSGA) entitled Review of the Embankment Stability at Buckeye Lake Dam. WSGA's review was performed on a 1987 report of the Buckeye Lake Project prepared by Dodson-Lindblom Associates (DLA) for the Ohio Department of Natural Resources. The issues addressed below concern the presence of sand seams within the embankment, the potential for piping, the results of stability analyses, and the potential for embankment saturation occurring at higher pool levels.

Embankment Materials

In WSGA's report, Section 2 - Embankment Soils, it is stated that the borings from DLA's 1987 report indicated that "sand and/or silt partings and seams were encountered in the embankment and foundation of the dam..." and that "... Boring 2A ... reported significant seepage through the sand seams within the embankment."

Boring B-2A was drilled in an area between the old, masonry wall and a more recent sheetpile wall that had been driven upstream of the masonry wall. Consequently, the soils encountered by this boring consisted of random fill placed as backfill against the sheetpile and they are not considered embankment fill. Boring B-2A also encountered concrete between depths of 9.0 and 10.5 feet which may have been part of the foundation for the old, masonry wall.

The remaining borings did not encounter sand seams within the embankment fill. Boring B-3 encountered a thin, sand lens at a depth of 10.8 feet but this lens is immediately beneath the embankment fill at the top of the foundation soils.

In general, the borings drilled through the original embankment encountered seepage near the base of the embankment or in the foundation soils immediately beneath the fill. In addition, the embankment fill encountered by the borings was cohesive (average fines content of 79%), and generally classified as damp to moist.

Consequently, it is believed that seepage at the dam is occurring through more permeable seams in the lake bottom and the lacustrine deposits beneath the embankment fill. The borings do not indicate significant seepage through the embankment fill.

Piping

Garner's report also indicates that piping is a significant hazard at the project. As mentioned above, it appears that seepage is occurring beneath the embankment rather than through the embankment. Because of the long seepage path length from the lake to the toe of the embankment and the low head, a seepage analysis was not performed as part of DLA's 1987 design. However, we did analyze the potential for seepage as a result of WSGA's comments.

Section 3 was analyzed since it was considered most critical, i.e., largest head and shortest seepage path length. The embankment was assumed to be impervious and seepage was confined to the foundation soils. This section was analyzed both with and without the existing sheetpile wall in place assuming the pool at the spillway crest elevation of 892. Even without the sheetpile wall, the exit gradient was 0.22, which results in a safety factor of 4.0 against piping. With the sheetpile added to the section, the seepage path length increases, and, obviously, results in an even higher safety factor against piping. We would generally consider a minimum safety factor of 3.0 to be adequate.

Stability

As part of DLA's 1987 report, four sections were planned to be investigated. All four of the sections were at locations along the embankment where seepage had been reported at higher pool levels. However, access to the boring locations at Section 1 was not possible and no borings were drilled for this section. In addition, at Section 3, permission to drill on the property where seepage was reported could not be obtained and only one boring was drilled at the top of the upstream slope near this property. Three additional borings were drilled along the fire lane about 100 feet west of the property.

The analyses performed for DLA's 1987 report were performed using the STABL2 slope stability program. This program used Janbu's method to calculate the factor of safety for the critical failure surface. In WSGA's review, stability analyses were performed with the STABL5 program using the Modified Bishop method to calculate the factor of safety. Consequently, we reanalyzed the cross-sections from the 1987 report using the UTEXAS3 slope stability program and the Modified Bishop method.

Of the sections analyzed for stability in the 1987 report, only Section 2 indicated marginal safety factors. These marginal safety factors were for very conservatively assumed phreatic conditions. The Corps assumes the maximum pool level at which a steady state seepage condition can exist is at the maximum storage pool, i.e., spillway crest elevation (EM 1110-2-1902, Stability of Earthfill and Rockfill Embankments, Table 2). The minimum required safety factor for this condition is 1.5. Summarized below are the results of stability analyses from the 1987 report, WSGA's review, and our reanalysis performed on Section 2 with the pool at spillway crest elevation (elev. 892).

Analysis	Method	Safety Factor
DLA's 1987 Report	Janbu	1.35
WSGA's Review	Janbu Modified Bishop	1.39 1.46
DLA's Reanalysis	Modified Bishop	1.41 (infinite slope) 1.48 (deep failure surface)

The safety factors from the analyses are essentially at or only slightly below the minimum required safety factor of 1.5. We believe that the calculated safety factors are adequate due to the location of the critical failure surfaces. Although the safety factors are slightly less than the required minimum, the critical failure surface in all of the analyses is located along the downstream slope, well downstream of the embankment crest.

It should also be noted that WSGA's report indicates concerns with seismic events causing instability at the dam. WSGA's report states that the calculated displacements during the design earthquake with the lake above elevation 895 will "likely be sufficient to fail the dam." However, the report also states that "With the pool at an elevation of 892, the embankment is stable and there is no displacement during the maximum earthquake."

During the 1987 investigation, pseudo-static analyses were not performed on the embankment due to its low height and the dam's location in an area of low seismic risk. The Corps' pseudo-static stability analysis for an earthquake condition is performed assuming steady-state seepage from the maximum storage pool level, i.e., spillway crest level (EM 1110-2-1902, Stability of Earthfill and Rockfill Embankments, Table 2). For this condition a minimum safety factor of 1.0 is required. Pool levels higher than the spillway crest are not considered for two reasons: pools will not remain above the spillway crest long enough to develop a steady-state seepage condition, and, the probability of a maximum seismic event occurring at the same time as a PMP event is extremely remote. Both DLA's and WSGA's pseudo-static analyses of the embankment assuming the pool at spillway crest level (elev. 892) and the occurrence of the maximum earthquake resulted in safety factors greater than 1.0.

Embankment Saturation

The analyses performed in the 1987 report with pools higher than the spillway crest level assume that the pools will remain at the higher elevations long enough to saturate the embankment and develop a steady seepage condition. This assumption is very conservative since the spillway was designed to release the majority of the PMP within 27 hours.

Using a typical correlation between head and seepage length developed by Cedergren, an estimate can be made for the time needed to saturate an embankment. Conservatively assuming a permeability value of 10^{-5} cm/s for the embankment soils (the average percent fines of the embankment fill samples tested was 79%, which would typically correspond to a permeability value of 10^{-6} cm/s or 10^{-7} cm/s). Cedergren's correlation indicates that higher pools would have to remain against the embankment for 140 days to develop a steady-state seepage condition.

Section 3 – No sheet piling
Pool – 892'

$i_{avg} = \frac{0.5'}{\frac{1.75' + 2.75'}{2}} = 0.22$

$F.S. = \frac{\gamma'}{i_{avg}\,\gamma_w} = \frac{54.6}{0.22 \cdot 62.4} = 3.98$