Analysis of a High Crib Wall Failure

Analyse de la rupture d'un mur de soutènement

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SUMMARY

A section of a crib wall, 34 ft high and concave in plan, experienced such severe deformations that it had to be demolished and rebuilt. A study showed that the central one of the three longitudinal footings which supported the skeleton of the crib had settled more than the outer ones. This reversed the usual direction of the wall friction along the rear face of the upper single cell part of the wall, reducing the factor of safety against sliding along its base to an unsafe value of 0.95, as compared to the 2.82 value computed for a conventionally directed wall friction force.

SOMMAIRE

Un mur de soutènement de 34 pieds de hauteur, qui avait une courbure concave en plan et qui était composé d'éléments en beton armé, a subi des déformations si sévères qu'il dut être démoli et reconstruit. L'étude démontra que la semelle centrale des trois semelles longitudinales, sur lesquelles reposait le squelette en béton armé du mur, avait subi un affaissement plus grand que ceux des deux semelles extérieures. Ce fait changea la direction du frottement du sol sur le dos de la partie supérieure du mur qui était plus étroite. En conséquence, le coefficient de sécurité contre le glissement latéral fut réduit de 2.82 à la valeur dangereuse de 0.95.

EARTH RETAINING CRIB WALLS built of precast reinforced concrete units are comparatively simple to analyse when their height does not require a width exceeding that of one cell (Tschebotarioff, 1951). Such crib walls easily adjust themselves to longitudinal differential settlements parallel to their face (Tschebotarioff, 1962). In recent years, attempts have been made to increase the height of crib walls to an extent requiring the use of two interlocking rows of cells in the lower portion of the wall in order to increase the width of its base. Such walls can be very sensitive to transverse settlements, however. This is illustrated by the following case of a concave 24-ft to 34-ft high wall (Figs. 1 and 2).

FIG. 1. General view of 34-ft high concave crib wall.

The upper part of the wall had noticeably bulged outwards (Fig. 3). As a result of this outward movement and of the concave curvature in plan of the wall, the expansion joints between double vertical rows of headers had widened (Fig. 4). This widening occurred only in the upper part of the wall, thereby giving another indication that the outward sliding had taken place only where the wall was one cell in width.

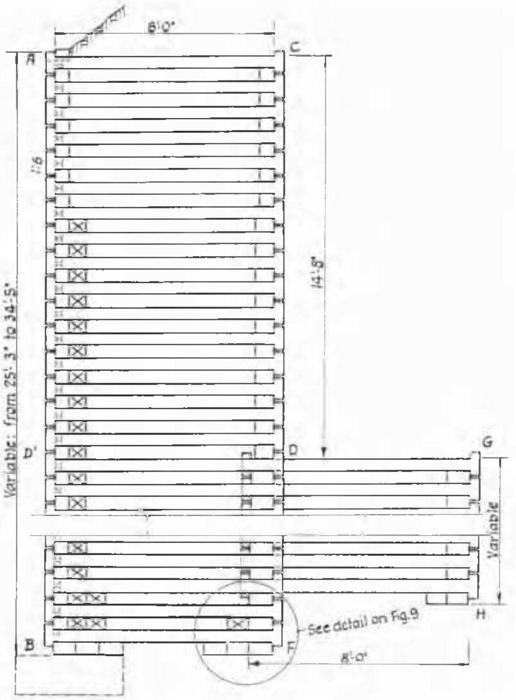

FIG. 2. Cross-section of crib wall as originally designed.

It should be noted that a convex (Fig. 5a) crib wall of approximately the same height in the vicinity did not show any signs of distress. The severe cracking of the reinforced concrete headers and stretchers of the concave concrete wall (Fig. 3) had to be attributed, therefore, to tensile stresses induced in the headers (Figs. 5b and 5d) as a result of the outward sliding (Fig. 5c) of the upper one-cell wide portion of the wall. This sliding was, therefore, the primary cause of the trouble. The original designers of the wall had detailed it (Fig. 2) and had analysed its stability in a conventional

FIG. 3. Outward bulge of upper part of crib wall.

FIG. 4. Opening of upper part of expansion joint.

manner (Fig. 6), computing a satisfactory factor of safety $F = 2.82$ against sliding along the surface where the sliding later actually occurred.

Field density determinations and laboratory tests were performed under the writer's direction indicating that the fill used within the cells and behind them was clean, well-packed sand with an angle of internal friction at least equal to the $\phi = 33°$ assumed by the original designers (Fig. 6). The soil beneath the crib wall was also compact sand.

An examination of the upper surface A–C of the crib wall (Fig. 2), however, indicated that the fill within the cells must have settled after it had been placed. Further, construction records showed that the placing of the fill within the upper part ACDD′ of the wall (Figs. 2, 6, and 7) was done in freezing weather when adequate compaction was not possible. However, the fill behind the wall was compacted by construction equipment passing over it.

The lowest value of the angle of internal friction determined in the laboratory for the loosest state of the fill was $\phi = 28°$. The actual slope of the fill surface immediately behind the wall was not as steep as was assumed in the original design (Figs. 6 and 7), but was appreciably flatter ($\omega = 12°$). By repeating the analysis of Fig. 6 with $\phi = 28°$, $\delta = +18°$, $\beta = -9°$, and $\omega = +12°$, a satisfactory factor of safety against sliding equal to $F = 2.1$ was obtained. Thus the low original shearing strength of the fill within the cells

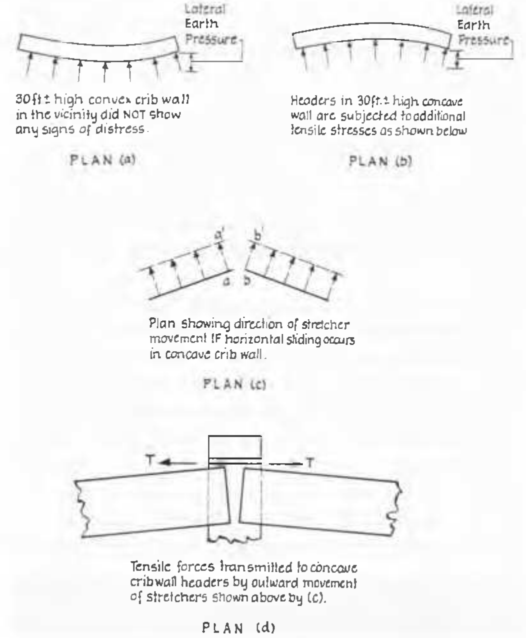

FIG. 5. Outward lateral movement of concave crib wall induces transverse tensile stresses in headers.

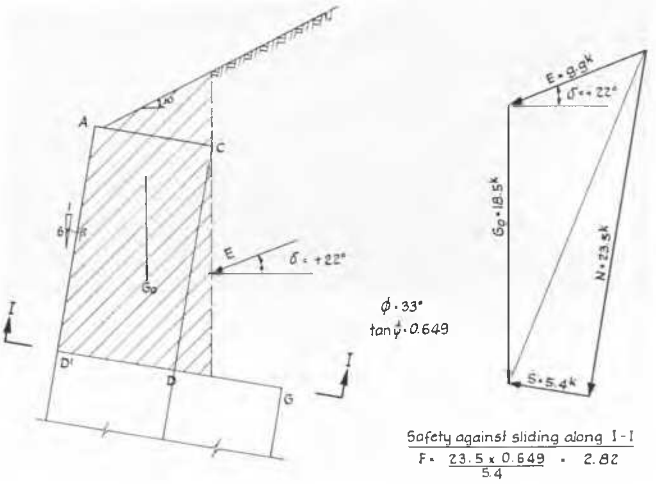

FIG. 6. Conventional analysis of upper single-cell section of crib wall.

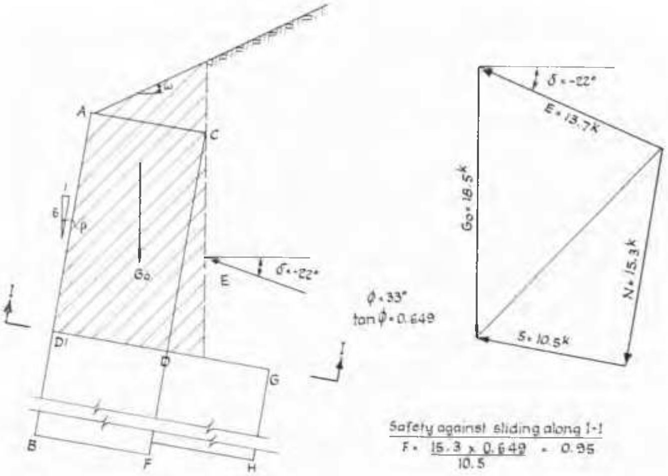

FIG. 7. Stability analysis of upper single-cell section of crib wall if CDF settled more than AD′B and GH.

could not explain the actual sliding. The following deductions, however, fitted all the observed facts.

Settlement of the fill within the cells was bound to produce so-called "arching" or "bin effects" within the cells. This, as well as the 1:6 batter of the crib, loaded its inner longitudinal wall CDF to a greater extent than the outer walls AD′B and GH (Fig. 2).

The greater loading of the central longitudinal wall produced its greater settlement as a consequence of which the conventionally assumed direction of the angle of wall friction ($+\delta$) was changed to ($-\delta$). The stability analysis was therefore repeated for this changed condition (Fig. 7), all other assumptions of Fig. 6 remaining unchanged. This analysis, shown on Fig. 7, indicated that the reversal of the direction of wall friction decreased the safety against sliding to $F = 0.95$. Actually this factor must have been even smaller when sliding began since the angle of internal friction must have been smaller than $\phi = 33°$ before seasonal temperature and saturation variations, in combination with shearing deformations, compacted the originally loose frozen sand fill to its present satisfactory density.

FIG. 8. Photo of crack illustrated by Fig. 9 (taken from opposite direction).

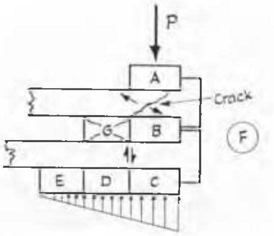

FIG. 9. Causes of shear cracks in headers at point F of crib wall (Fig. 2).

The tendency towards greater settlement of the central longitudinal wall of the crib skeleton was accentuated by the details of its foundation. In accordance with the customary assumption that a crib wall acts like a massive gravity wall, a substantial continuous reinforced concrete footing was provided at its toe. It is shown by broken lines on Fig. 2. However, only three precast stretcher units—marked E, D, and C on Fig. 9—were laid down below the longitudinal centre wall. They were not structurally connected to each other in a transverse direction, except by the headers. A numerical estimation of the downward force P, transmitted by the longitudinal wall of the crib skeleton in the case of some soil "bin action" within its cells, indicated that the headers above and below the stretchers B and the block G could not have transmitted the resulting loads to the soil through the stretchers E, D, and C without cracking, as shown on Fig. 9.

To check this point, three cells were fully excavated and the anticipated cracks were actually found in the headers (see Fig. 8). The measured deflection of the headers indicated that the central longitudinal crib wall must have settled at least two inches more than the outer face of the crib.

CONCLUSIONS

1. Concave crib walls are much more susceptible to damage by transverse deformations than are convex walls.
2. The reinforced concrete skeleton of crib walls over 20 feet high will not act as one massive unit with its earth fill unless the latter is compacted with special care.
3. Structural detailing should aim at preventing the greater settlement of the central longitudinal wall of the crib skeleton since such settlement may reverse the direction of friction between soil and the upper part of the wall, thereby strongly decreasing its resistance to lateral sliding.

REFERENCES

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