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JULY/AUG 2017 | GROUND VIBRATIONS

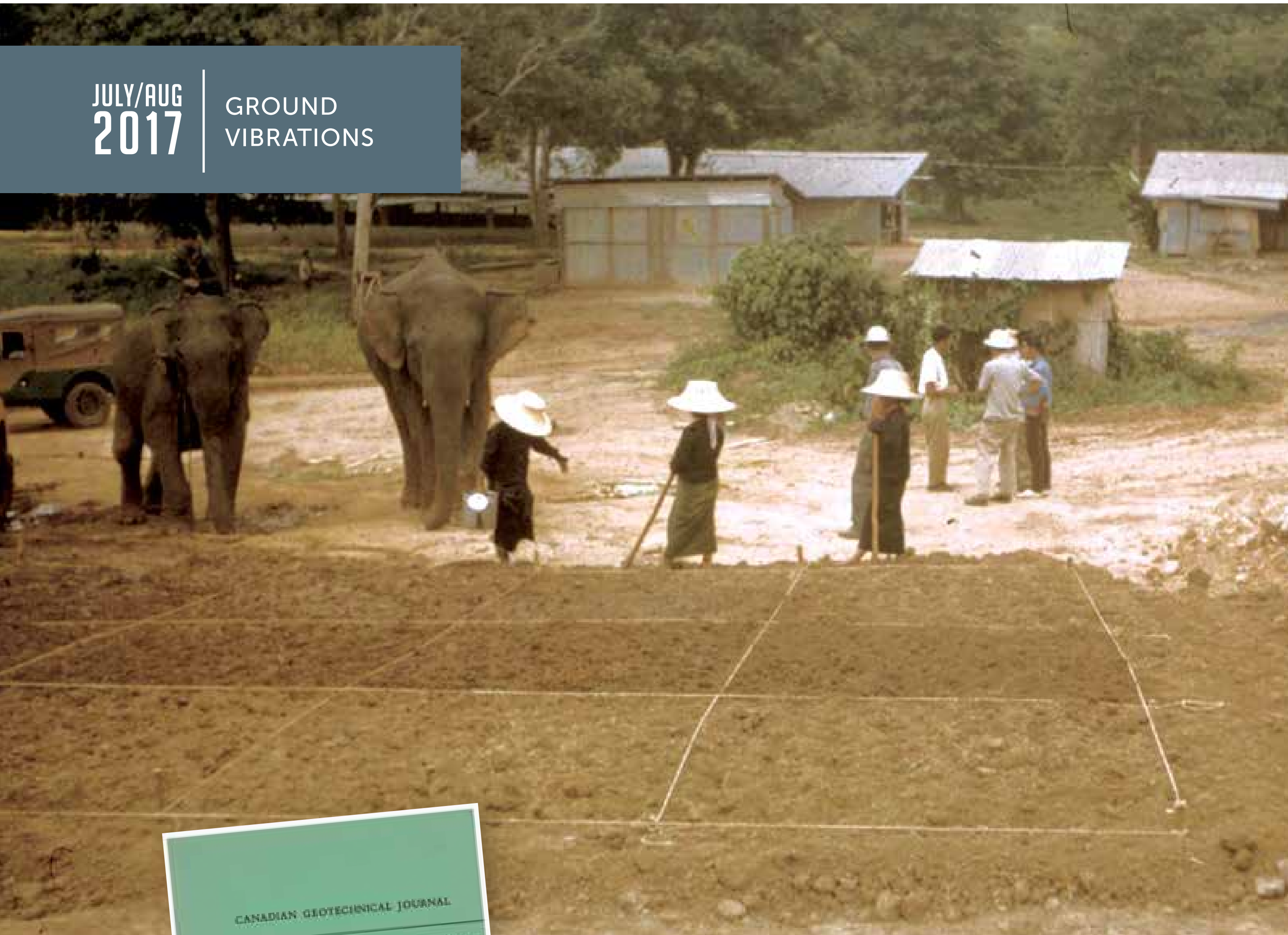


Figure 1. **General view of test lift before start of compaction.**

Editor's Note: For some time, I've wanted to start a new column in *GEOSTRATA* dedicated to little-known facts about our profession. But this proved to be harder to get off the ground than expected. After searching for just the right topic, I finally came across this highly entertaining account from the August 1967 *Canadian Geotechnical Journal* (Vol. IV, Number 3) that described an experiment in Thailand using a locally available resource – elephants – to compact soil. It turns out that elephants may be plentiful in that country, but they don't make very effective compactors. Now we know! Many thanks to Canadian Science Publishing for granting us permission to republish this piece, and to the author, who graciously wrote us an update to the original.

The Uselessness of Elephants in Compacting Fill

By Richard L. Meehan, *Soils Engineer, LeMessurier Associates, Inc., Boston* (at the time of original publication)

Erosion of irrigation canal embankments during the wet season is a perennial problem in Northeast Thailand. Grass cover is often difficult to establish because, among other reasons, the embankments are convenient pedestrian thoroughfares. Proper compaction of the embankments is an obvious remedy which is seldom applied for lack of suitable compaction equipment.

Maintenance of embankments had become a major problem along the main canal and laterals of the Lam Pra Plerg Project, an irrigation development located 60 kilometers south of the town of Korat. It occurred to the frustrated field engineers that local unemployed elephants might be recruited at a reasonable rate to perform the compaction. Although several opinions were offered on the efficacy of such a means, no record of the performance of elephants as compactors was discovered. Accordingly, it was decided to resolve this controversial question by undertaking a modest field investigation.

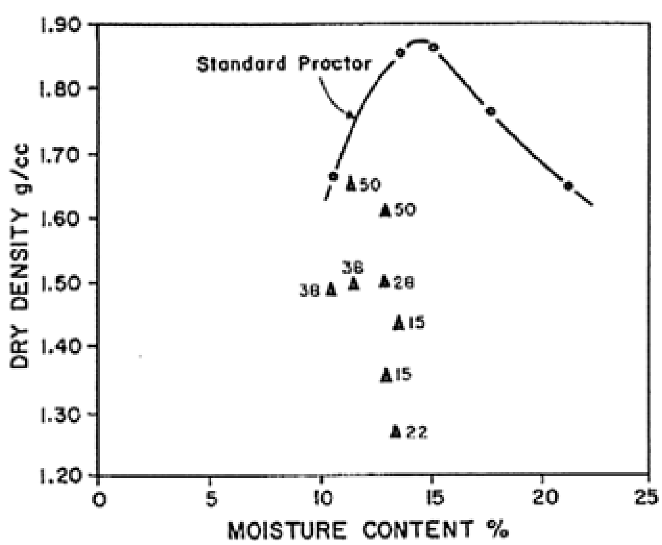
Elephas maximus, the Asian elephant, is regarded with particular affection by the Thai, who not only share our delight at the wondrous sight of two tons of animal flesh, but also know their elephants as dependable workers with an unparalleled capability for dragging valuable timber from the thickest jungles. The enthusiasm amounts to a national tradition; the distinguished Siamese monarch King Mongkut, upon receiving word of the American Civil War, offered President Lincoln a battle-trained squadron of elephants to crush the opposition.[1] It was no surprise, then, that as the day of the field test approached, all concerned looked forward to the beasts proving themselves the equals of imported machines.

[1]The offer was politely declined. Lincoln probably knew that elephants panic in the face of cannon fire.

Procedure

A fill stockpile area at the headworks was selected as a convenient site for the trial. The test material was a sandy clay of low plasticity from a nearby excavation. Natural moisture content was 4 to 5 per cent dry of optimum. The soil was spread by hand in a 20 cm lift over an area 9 meters square, and divided by string into 9 square sections (see

Figure 2. **Field densities and moisture contents (numbers adjacent to symbols show the number of elephant passes).**



Types of Soil Compaction

Pneumatic rubber-tired roller

Sheepsfoot roller

Vibratory smooth-wheel drum roller

Elephant

Equipment photos courtesy of Atlas Copco Group.

Figure 1), or 3 east-west lanes of 3 meters width intersected by 3 similar north-south lanes. Different moisture contents were obtained in each of the north-south lanes by hand sprinkling, and different compactive efforts were achieved in the east-west lanes by varying the number of coverages. Two elephants, a cow and a bull, were used. In addition to the handler, a qualified soils technician rode on each elephant during the time that the animal was on the test lift. The intention was to direct the elephants in file back and forth through the east-west lanes a predetermined number of times.

Unfortunately, the large number of people that crowded onto the test section to watch the operation, the sharp turns required, and the differing dialects of the handlers and technicians confused and perplexed the elephants, so that it became necessary to remove the more excitable cow from the area. In general, the test was completed as planned, although it was necessary to increase the number of passes well above original expectations. At the completion of the test, field density determinations (sand cone method) were made in each of the squares formed by the intersecting lanes.

Results

Field densities and moisture contents are plotted along with the Proctor density-moisture content curve in Figure 2. Numbers adjacent to the plotted points designate the number of elephant passes. It is clear from the test results that this method of compaction fails to produce adequate density. This is explained as follows:

1. The weight of the animal is supported by three legs, even as it walks. The area of the imprint of each foot is typically 175 sq. cm, so that its weight is distributed over an area of about 525 sq. cm. Assuming a total weight of animal of 2000 kilograms, the applied pressure is 3.8 kg/sq. cm (54 lb./sq. in.). While this compares favourably with tire pressures of pneumatic rollers, the rate of coverage is much slower, i.e., a far greater number of passes is required for comparable coverage.
2. An elephant quickly learns to place its feet on precompacted areas and to avoid the softer uncompacted areas. The animal explores the terrain ahead with its trunk, a remarkable sensory organ,[2] and generally will place its feet on or near previous imprints. Strenuous control by the handler is required to obtain uniform coverage.

It was concluded that elephants are inefficient compactors, even considering the local low cost (current rate of rental for one elephant and handler is $5 per 6-hour day). Water buffalo, also in abundant supply, are thought to be a more promising solution, although no field trials have been made to evaluate this method to date.

[2]Elephants "see" the ground by feeling with the trunk and have a blind spot which is out of the normal range of both eyes and trunk. The animals may be kept out of gardens by stringing a wire horizontally two meters above ground. They are able to feel the wire, but cannot evaluate this invisible barrier and retreat in confusion.

Bu Hua Chang village in 1963.

Author Update

Fifty-four years after my elephant compaction experiment, I'm living in that same Thai village of Bu Hua Chang (translation: "Elephant Head Village"). The place is much modernized; village folk no longer rely on fortune tellers for medical diagnoses or measure happiness in fruit trees. Children now, typically one or two per family, go off to be airline pilots, nurses, dataviz geeks, and Coca-Cola sales managers.

I live beside the irrigation canal a mile downstream from my Lam Pra Plerng earth dam, in the middle of the village that we transplanted from its former site on the hills flanking the reservoir, the only safe place where I could find enough earth fill to build the dam. My wife and neighbors sometimes ask me whether the dam could fail someday and drown us all. Fifty years ago, I would have told them not to worry, as we had mightily compacted that soil with American machinery; I knew it was very tight and solid. Compaction, it seemed to me then, was the key; my engineering professors and elders, disciples of Terzaghi himself, pointed out that we could credit compaction with building airfields for those heavy bombers that won the war.

But it wouldn't be long before I learned that my meager knowledge of flow nets and the Proctor test, along with an inflated belief in American power and expertise, was not a sufficient basis for designing and building earth dams.

Dick Meehan today.


Lam Pra Plerng Dam looking south.

Shortly after my arrival on the project, prominent engineer Preston T. Bennett visited the dam site and opened the first cracks in my confidence.

Bennett had devised a mathematical approach to describe seepage patterns that developed in the 1930s under Mississippi River levees. He knew the importance of geological details in defining the limits of his theory. He believed that the continuity of natural "blankets" of fine-grained soil should not be broken on the waterside of a levee or dam by borrow pit excavations. High seepage forces were the enemy of downstream or landside foundation and abutment stability, especially for sands and silts, however well compacted. But I knew nothing about these matters in those days and was ignorantly exploring for borrow pits in the floodplain upstream from the dam site. Bennett, standing on the abutment of the dam as the Thai engineers watched us, rebuked me for this error. My elephant compaction story brought no smiles to this stern engineer's face. Moreover, it was determined that I was unaware that the locked tin shack a few steps away from us contained precious rock cores that had been retrieved in an abutment drilling program years before. Had I not studied those for evidence of open rock jointing in the brittle sandstone abutments?

But humiliating as this was, the memory of it stayed with me and became the basis for my diagnosis, some 30 years later, of a series of levee failure disasters in California. Furtive gold mining excavations by local contractors were the cause of one failure in Marysville during the gold price spike of the 1980s. I knew that the failure was entirely predictable via Bennett's method of analysis, as was a similar nearby disaster a few years later, where misguided government agencies had approved a waterside excavation to create habitat for a species of beetle. Quicksand had developed beneath the toes of the levees subjected to high seepage forces. Based, in part, on my testimony, California courts determined that government had failed to meet reasonable standards of practice, and state law was changed to burden the state thenceforth with absolute liability. Bennett's lecture to me had led to significant change in California law.

However inadequate my own experience might have been, it is clear in retrospect that the engineering profession


Elephants outside Meehan's bedroom in 1963.

in 1963 was short on knowledge of field seepage force dangers. I had once worked under John Lowe on the design of Tarbela Dam, drawing flow nets for various arrangements of partial cutoffs and anti-seepage blankets. Lowe was a fine engineer, but the hundreds of sinkholes that developed on the first filling of Tarbela in the mid-1970s were a serious fright: "I find myself holding a tiger by the tail," he said. In Chile a year or two later, I scouted a similar deep bouldary valley high in the Andes, and the proposed dam plan there was abandoned, perhaps for the best.

Meanwhile in 1963, as we began construction at Lam Pra Plerng with the impressively heavy yellow dozers, scrapers, and compactors that eventually arrived from the U.S., the Baldwin Hills Reservoir Dam, designed and supervised by Ralph Proctor himself, collapsed in downtown Los Angeles. Confusion and disagreement broke out among the disciples of Terzaghi (he had died that year) as to the cause of this disaster, but overcompaction of fill was later plausibly implicated.

Not long after, in 1976, the Teton Dam, a much larger version of the Lam Pra Plerng project, failed. The cause was the same: excess seepage forces acting on compacted, but brittle earth fill on one abutment. The failure happened at a point that was, from a geomechanical point of view, a scaled-up version of conditions at my Thai dam. Revisiting Thailand and my old village a year or two later, I was much disturbed at the news that the Lam Pra Plerng Dam, on filling, had in fact experienced a slide in the fill at an analogous point at the abutment. The scar had been dressed up, and now the dam was scheduled for a raise. These days looking up from my house at the heightened dam, I sometimes think that it might be prudent to do a flood routing analysis.

History since those years has taught us that seemingly great power and strength may bear the seeds of weakness. Elephants are not, after all, fierce kings of the jungle, but docile creatures struggling to maintain difficult thermal balance with their environment by minimizing energy expenditure. My attempt to harness these noble creatures to subdue nature had not succeeded, but I am lucky to have profited in some ways from these lessons. GS