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# Ground-subsidence study near Española and recommendations for construction on collapsible soils

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A six-month-long ground-subsidence investigation, undertaken by New Mexico Bureau of Mines and Mineral Resources engineering and environmental geologists, was concluded in June. The investigation was conducted to determine the cause(s) of ground subsidence and to suggest possible remedial measures in the El Llano area, northeast of Española. In November 1985, El Llano residents had alerted state workers to rapid soil subsidence that disrupted utilities and caused differential settlement and major cracks in their houses, and shortly thereafter the area was declared a state emergency (Shaw and Johnpeer, 1985). Collapsible soils were found to be the major cause of the subsidence. The geologically young, unconsolidated, porous soils in the area tend to reduce in volume when they become wetted from natural or human sources. Sources of wetting included rainfall, utility leaks, lawn irrigation, and septic tanks. The word soils is used here as an engineering term, which has been defined as "naturally occurring superficial deposits overlying bed rock" (International Conference of Building Officials, 1982).

The tremendous amount of data generated in the course of the study has enabled geologists to provide recommendations for builders who want to stabilize collapsible soils before building, homeowners who want to prevent soil collapse near their homes, and regulatory state agencies who may want to change building codes to address the collapse phenomenon. The following is a brief summary of the final phase of the investigation, the geotechnical ground-stabilization study (G.G.S.S.), and some recommendations for avoiding or alleviating soil collapse problems. Soil testing is required in local areas where collapse may occur because soil conditions can differ widely even within small areas (Johnpeer et al., 1985a, b).

### Geotechnical ground-stabilization study

The G.G.S.S. was done to demonstrate the direct relationship between ground wetting and subsidence, to test a possible stabilization technique (induced hydrocompaction), and to examine the performance of contrasting concrete-foundation designs. The implications of this study for retarding soil-collapse damage to structures in developed areas are significant.

The first part of the G.G.S.S. required injecting water into the subsurface soils at three areas (Fig. 1): two areas (1 and 3) were located east of El Llano acequia where the subsurface soils have not been wetted significantly and where the soils were suspected to be highly collapsible. The third area (2) was located west of the acequia, where the ground has been irrigated for at least 300 years (Johnpeer et al., 1985a, Appendix XVI). It was suspected that soils there had already collapsed substantially because of centuries of intermittent wetting by irrigation water. Therefore, this area was used as a control.

Figures 2, 3, and 4 illustrate the dramatic results of the experiments. The main difference between areas 1 and 3 was the depth of the water-injection wells. At area 1 (Fig. 2) the injection well was 30 ft deep, with two shallow (10-ft deep) wells close by; at area 3 (Fig. 4) the injection well was 10 ft deep. Water injected into the deeper well at area 1 consolidated the deep soils rather than the shallower, near-surface soils; therefore, surface subsidence did not occur initially. However, after water was injected into the shallow, 10-ft deep wells, subsidence did occur at area 1 (Fig. 2). This shows that the entire soil section (approximately 30 ft thick) is collapsible.

At area 3 (Fig. 4) subsidence occurred within 7 days even though considerably less water was injected there than was injected at area 1 (Table 1). The near-surface soils (up to 15 ft deep) absorbed most of the water, which led to rapid soil collapse. This area most accurately represents the situation found around a house where water seepage or leakage occurs at fairly shallow (less than 15 ft) depths. The volume of water (7,000 gal) required to induce surface subsidence at area 3 is approximately equal to the amount of water used by a family of four in one month. Subsidence features observed by investigators elsewhere in the El Llano area have reportedly formed equally fast.

At area 2 (Fig. 3) subsidence did not occur even though the subsurface monitoring indicated that the volume of soil wetted was consistent with the volume wetted at areas 1 and 3 (Johnpeer et al., 1985b). The experiment at area 2 was continued until the total water injected was 2.5 times as much as the amount injected at area 3 (Table 1) and it was apparent that collapse would not occur. As noted above, the soils at area 2 have been wetted for a long time, and soil collapse in ☞

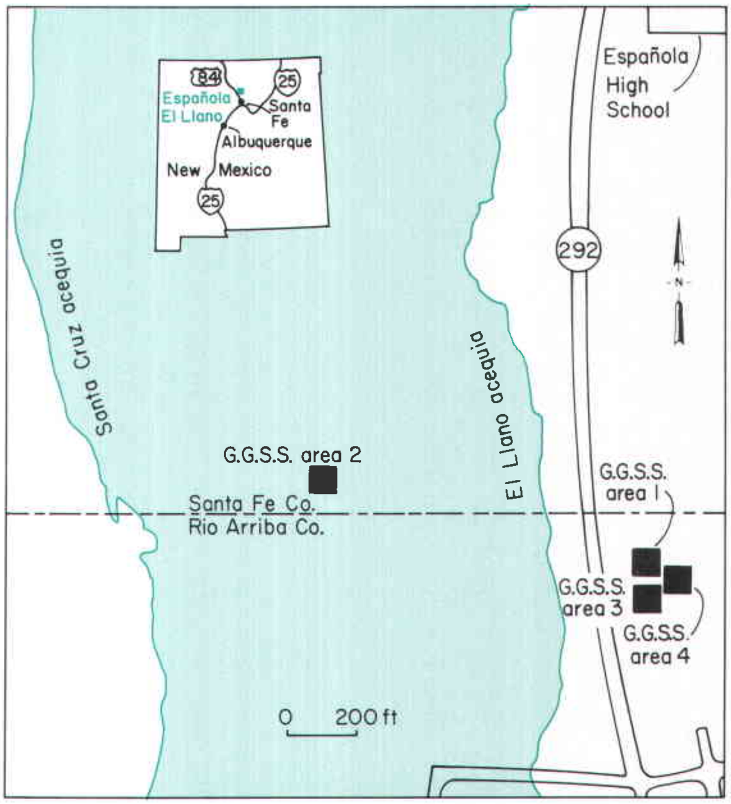


FIGURE 1—Location map of the G.G.S.S. areas. The shaded region has been irrigated for at least 300 years; the subsurface region east of El Llano acequia has not been wetted significantly. A more comprehensive map of the study area can be found in Shaw and Johnpeer (1985, fig. 1, p. 32).

FIGURE 2—G.G.S.S. area 1 after deep injection of water had ceased. Subsidence is evident, although not as dramatic as the subsidence that occurred at G.G.S.S. area 3.

FIGURE 3—G.G.S.S. area 2 a few days before water injection was stopped. A berm was built around the well to facilitate water injection, and, even though the soils were thoroughly saturated with water, no subsidence occurred.

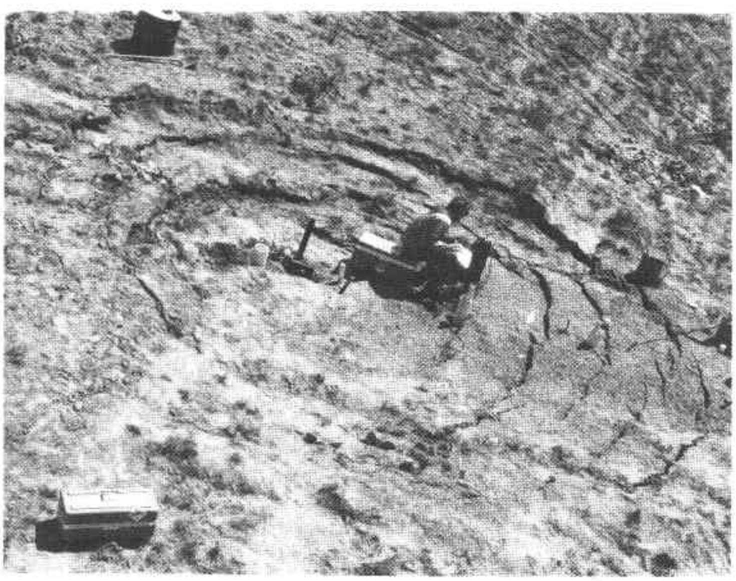

FIGURE 4—G.G.S.S. area 3 after water injection was stopped. Subsidence started to occur when about 7,000 gal of water had been injected, which was 7 days after water injection began. Note the concentric steps of subsidence as one looks farther and farther away from the water-injection well in the center.

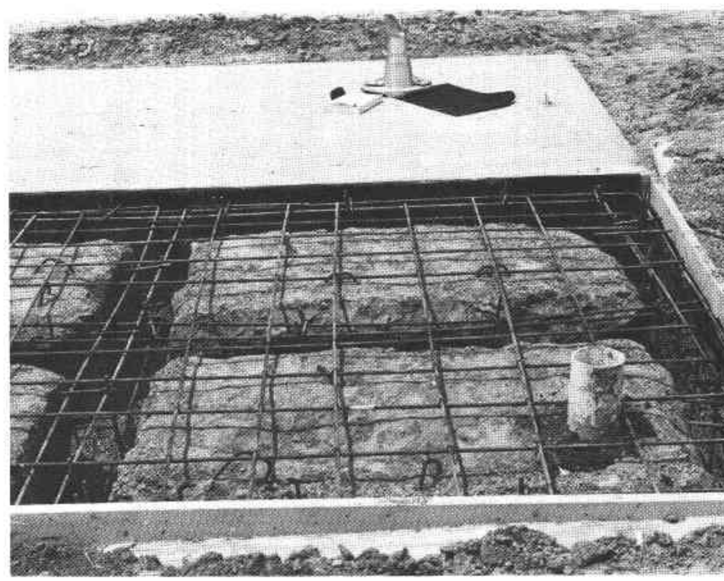

FIGURE 5—Reinforced BRAB foundation at G.G.S.S. area 4 before the concrete was poured. This type of foundation is recommended for new structures built on collapsible soils because of its strength and durability, which would allow one end to be elevated if differential settlement occurred.

TABLE 1—Comparison between the amount of water injected for a given time period at each G.G.S.S. area and the resulting amount of subsidence, if any. See Fig. 1 for location of the areas; **NA**, not applicable.

| G.G.S.S. area | Maximum depth of injection wells | Water required to induce settlement (gal) | No. of days to induce settlement | Total water injected (gal) | Duration of experiment (days) | Amount of subsidence |
|---|---|---|---|---|---|---|
| 1 | 30 | 21,294 | 42 | 42,996 | 63 | 0.5 ft |
| 2 | 30 | NA | NA | 24,567 | 84 | NA |
| 3 | 10 | ~7,000 | 7 | 16,880 | 16 | 2.2 ft |
| 4 | 10 | 19,881 | 13 | 107,191 | 28 | 1.4 ft |

these irrigated lands between the two acequias (Fig. 1) appears to have ceased, although some potential for subsidence may still exist.

The second part of the G.G.S.S. could affect the state building code for areas where collapsible soils are present. This experiment was conducted at area 4 with two contrasting concrete foundations. The two foundations (approximately 10 ft × 15 ft × 4 inches) were constructed side-by-side approximately 50 ft from areas 1 and 3 in similar-type soils (Fig. 5). One foundation was constructed with footings and rebar support common to foundations in the El Llano area. The other foundation was constructed as a BRAB foundation, with more extensive footings and an interlocking rebar "cage" that adds greatly to the strength of the foundation. This foundation was devised by the Building Research Advisory Board (BRAB) for use on soils that expand when wetted. However, the foundation appears to function equally well when used with structures built on collapsible soils. Both foundations were weighted with sand bags to simulate the weight of a building.

A significant advantage of the BRAB foundation-type design is that it remains intact subsequent to any differential settlement of soils. In contrast to conventional foundations, its strength allows it to be releveled if differential settlement should occur. Any structure on the BRAB foundation remains essentially undisturbed. Conventional foundations commonly fracture when subjected to the stresses that arise from differential settlement. The 15 monitoring wells around the foundations (Fig. 6) made it possible to trace the subsurface water plumes and to measure the amount, the timing, and the depth of the settlement.

The foundations began to subside uniformly within 13 days after 19,881 gal of water had been injected into the five water-injection wells (10-ft deep). Injection of water was continued until monitoring confirmed that soil collapse had largely ceased (Fig. 7). A total of 107,191 gal of water was injected into the wells during the experiment.

The foundations were carefully monitored during the 12 days that surface settlement and accompanying cracking occurred; 1.4 ft of surface collapse was induced during that time. The average rate of collapse was initially 3 inches per day, but soon decreased to less than 0.5 inches per day. More important, the foundations settled evenly; no differential settlement was detected and neither foundation exhibited any cracks.

This is the first time, known to us, that induced hydrocompaction has been used to successfully settle a foundation and, in the process, stabilize soils beneath an existing foundation. The success of this experiment demonstrates that induced hydrocompaction may be a viable technique for stabilizing relatively shallow (less than 30-ft-deep) collapsible soils beneath existing, full-scale structures. Although existing structures could now be settled uniformly in some areas, it would be much more effective and efficient if building code officials recommended, and perhaps required, *pretreatment* of soils in collapse-prone areas of New Mexico.

## Recommendations for development on collapsible soils

Stabilization of collapsible soils should be a prime objective *before* construction. In undeveloped areas, relatively inexpensive and routine measures can be implemented. Unfortunately, much construction in the El Llano area and elsewhere has taken place with little or no regard for the subsidence hazard posed by collapsible soils. In developed areas, the ☞

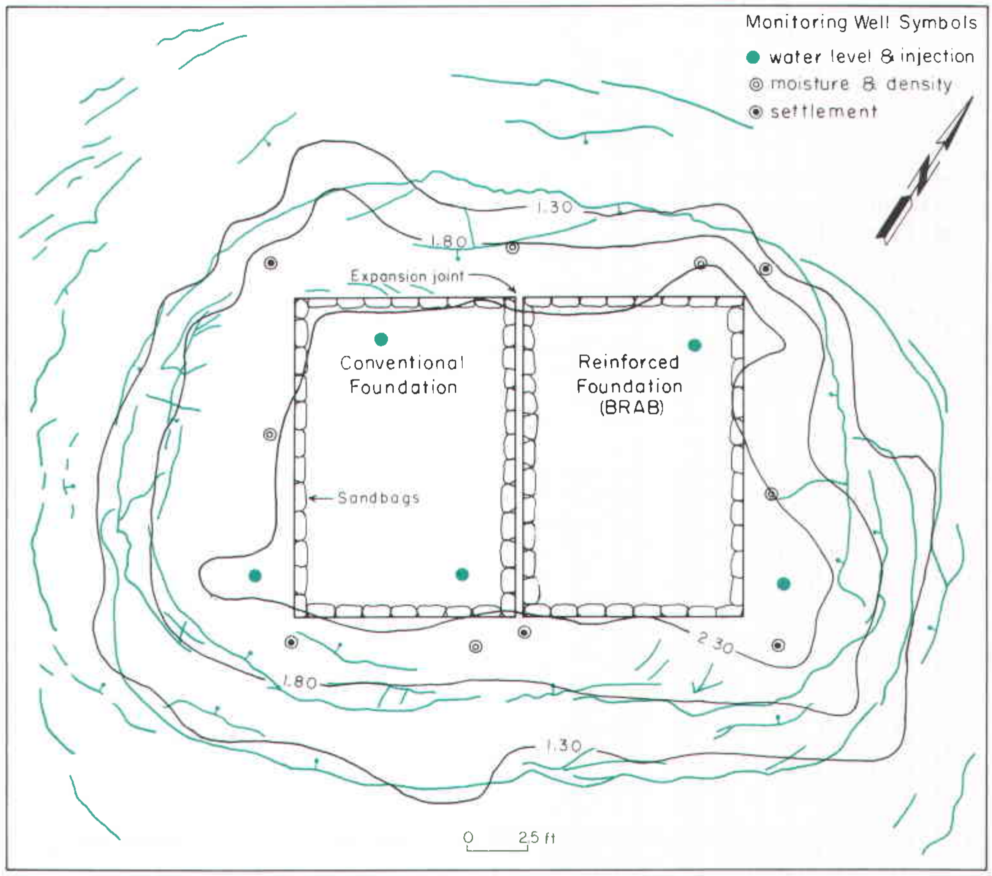


FIGURE 6—Sketch of the foundations, monitoring wells, contour lines (black), and crack development (blue) at G.G.S.S. area 4. The water-injection wells were situated so that the circumferences of the wetted areas would overlap. The area that was expected to be wetted by each injection well was derived from the major area actually subsided at area 3 (Fig. 4). Water-injection wells would have to be angle-drilled if this procedure was used to subside a full-scale foundation. The contour lines represent depth below datum elevation of 5,734.5 ft; contour interval is 0.1 ft.

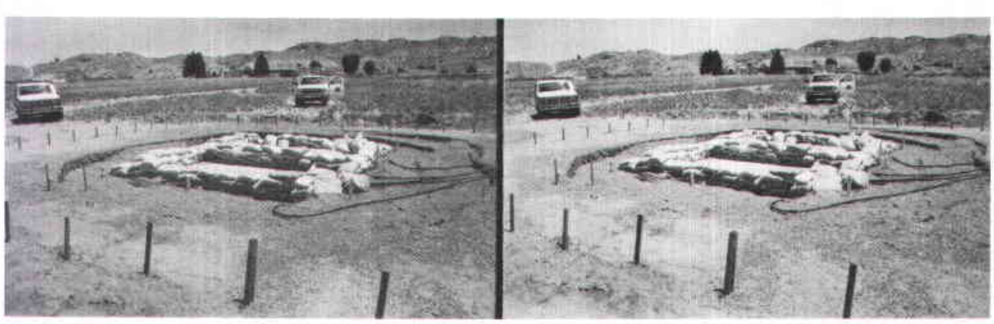

FIGURE 7—Stereo pair of the concrete foundations at G.G.S.S. area 4 after 1.4 ft of subsidence had occurred. The subsidence and ground cracks can be viewed best by using stereo glasses. Note the concentric steps of subsidence similar to those seen at area 3 (Fig. 4).

mitigative measures are much more expensive and may be difficult to implement. Therefore, the approach recommended is to prevent moisture from reaching the soils beneath the foundation. This preserves the inherent dry strength of the soils, which is usually sufficient to support relatively small structures such as houses. More detailed recommendations follow (*see also* Johnpeer et al., 1985a, b).

### Undeveloped areas

Soil testing of the construction area is necessary because collapse potential varies greatly with depth even within small areas. Identified collapsible soils should be compacted before construction begins. Settlement can be induced by injecting water into the subsurface soils and allowing the area to subside. The subsided area should then be backfilled and compacted. If it can be determined that all the collapsible soils are shallow (1–10 ft deep), they could be excavated, backfilled, and compacted. Unfortunately, collapsible soils often extend below 10 ft, which makes excavation very expensive. If the collapsible soils exist to a considerable depth, piles can be driven through the collapsible layer to give the structure adequate bearing capacity. This method not only stabilizes the foundation but tends to densify the surrounding soils, which further improves subsurface conditions. Drainage away from the foundation can be improved by building the structure on an elevated pad.

In some places it may be more effective and less expensive to compact the soils using dynamic compaction. This method, which has been used in New Mexico, involves lifting a heavy weight and dropping it to the ground surface (Lovelace et al., 1982). In any case, foundations should be designed so that they can withstand some settlement without sustaining structural damage. Use of a reinforced foundation (such as the BRAB foundation) does not add considerably to the cost of a new structure, and the foundation could be releveled if subsidence occurs. Remedial measures suggested for already developed areas would also help prevent or lessen the severity of soil collapse.

### Developed areas

Drainage control is critical in developed areas because a definite correlation exists between areas of poor drainage and sites of soil collapse. Corrective measures that are relatively inexpensive and easy to implement include: 1) landscaping the area around a structure so that natural runoff is enhanced, and using southwest desert landscaping to avoid sprinkling of lawns; 2) planting trees and plants away from foundations; 3) installing rain gutters with downspouts that direct water away from the foundation; 4) placing an impermeable geomembrane "apron" around the foundation to prevent water infiltration (this apron must be a special, heavy-duty material to ensure both a water-tight seal and durability); and 5) abandoning use of septic tanks near or uphill from foundations because they continually add moisture to the soil at shallow depths. The typical city sewage system is not necessarily a better alternative to septic tanks. An adequate sewage system, in this case, must be strengthened with specially welded joints and frequently maintained to prevent leaks. Water lines also must be maintained frequently for the same reason.

Other possibilities for stablizing foundation soils are both expensive and experimental. One method involves injecting the soil beneath a foundation with a thin, watery mixture of grouting material that densifies loose soils when it dries. This method is effective only if the grout reaches all the way through the collapsible sediments. In El Llano this depth is at least 30 ft. Induced settlement of a foundation, similar to the experiment described above is now another viable possibility.

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## USGS

TOPOGRAPHIC MAPS—NEW (scale 1:24,000)

| | yr | lat. | long. | contour (ft) |
|---|---|---|---|---|
| Bootleg Ridge | 1978–84 | 32°15′ | 103°37′30″ | 10 |
| East Lake | 1978–84 | 32°15′ | 103°15′ | 10 |
| Española | 1978–84 | 35°52′30″ | 106° | 20 |
| Frijoles | 1978–84 | 35°45′ | 106°15′ | 20 |
| Grama Ridge | 1978–84 | 32°22′30″ | 103°30′ | 10 |
| Guaje Mountain | 1978–84 | 35°52′30″ | 106°15′ | 20 |
| Ironhouse Well | 1978–84 | 32°37′30″ | 103°30′ | 10 |
| Laguna Gatuna | 1978–84 | 32°30′ | 103°37′30″ | 10 |
| Laguna Gatuna NW | 1978–84 | 32°37′30″ | 103°37′30″ | 10 |
| Lea | 1978–84 | 32°30′ | 103°30′ | 10 |
| Oil Center | 1978–84 | 32°22′30″ | 103°15′ | 10 |
| San Simon Ranch | 1978–84 | 32°22′30″ | 103°22′30″ | 10 |
| San Simon Sink | 1978–84 | 32°15′ | 103°22′30″ | 10 |
| Tip Top Wells | 1978–84 | 32°15′ | 103°30′ | 10 |
| White Rock | 1978–84 | 35°45′ | 106°07′30″ | 20 |

INTERMEDIATE TOPOGRAPHIC MAPS (scale 1:100,000)

| | yr | lat. | long. | contour (m) |
|---|---|---|---|---|
| Columbus (BLM) | 1974–81 | 31°30′ | 107° | 20 |
| El Paso (TX–NM–Mex.) | 1977–83 | 31° | 106° | 20 |
| Ruidoso | 1974–84 | 33° | 105° | 50 |

## 6th International Conference on Basement Tectonics

The nature, origin, and reactivation histories of large-scale fractures and other major structural features in the earth's crust will be investigated at this conference, which will be held in Santa Fe, New Mexico, September 16–20. Technical sessions focusing on the geological, geochemical, geophysical, and theoretical aspects of interpreting fracture systems will be highlighted with field trips through the spectacular Grand Canyon region. Special field trips will be held for several days before and after the conference. Proceedings of the conference can be obtained by writing to International Basement Tectonics Assn., 675 South 400 East, Salt Lake City, Utah 84111 (801/328-8541). For more information on the conference, accommodations, field trips, and rates, write or call M. J. Aldrich, General Chairman, MS-D462, Los Alamos National Laboratory, Los Alamos, New Mexico 87545 (505/667-1495).