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Foundation stabilization of Jackson Lake Dam La stabilisation des fondations du barrage de Jackson Lake

A.PUJOL-RIUS, Geotechnical Engineer, Morrison-Knudsen Engineers, San Francisco, California, USA
P.GRIFFIN, Chief, Embankment Dams Dept., Morrison-Knudsen Engineers, San Francisco, California, USA
J.NEAL, Project Engineer, National Projects, Inc., Moran, Wyoming, USA
O.TAKI, President, S.M.W. Seiko, Redwood City, California, USA

SYNOPSIS: Key geotechnical aspects of the planning and construction of the foundation stabilization for Jackson Lake Dam, Wyoming, are summarized. Now under construction (as of June 1988), this work is being accomplished using both dynamic compaction and the Soil Mixing Wall (SMW) technique; it is the first U.S. application of the innovative SMW ground improvement technology.

BACKGROUND

Located at the foot of the Teton Mountains within the Grand Teton National Park, Jackson Lake Dam consists of a 4,500-foot-long north embankment, a 222-foot-long concrete spillway spanning the Snake River, and a 150-foot-long south embankment. The dam was constructed in stages by the U.S. Bureau of Reclamation (USBR) between 1906 and 1916. A schematic plan view of the dam showing the limits of the various construction stages is shown in Fig. 1. The north embankment, a 49-foot-high hydraulic fill structure, was founded on generally loose, saturated alluvial soils consisting of a complex series of interfingered gravel, sand and fines deposits, extending to a depth of over 100 feet.

The dam is located in an active seismic region 4 miles east of the Teton Fault Zone, which runs along the base of the Teton Mountains and is believed capable of a 7.5 Richter magnitude earthquake. USBR seismic analyses indicated that the loose, cohesionless soils in the north embankment and its foundation could be susceptible to liquefaction under strong earthquake shaking, potentially resulting in catastrophic failure of the embankment. Consequently, dam safety remedial modifications were planned.

Originally, a new dam four miles downstream from the current dam was envisioned (Welsh et al, 1987). However, public outcry over the inundation of popular river rafting areas and concerns over wildlife preservation outweighed cost considerations and led to implementation of a repair plan involving excavation of the north embankment, stabilization of the foundation, and dam reconstruction using suitable, properly compacted fill materials.

Stage I construction, completed in early 1987, involved excavation of the northern two-thirds of the north embankment and densification of a portion of the foundation by dynamic compaction to an approximate depth of 40 feet. Stage II construction, to be completed in late 1988, includes removal of the remaining embankment, stabilization of the 1900-foot-long southernmost section of the foundation to maximum depths of about 100 feet, construction of a 4,000-foot-long cutoff wall along the upstream toe of the dam to a maximum depth of about 110 feet, and fill reconstruction (Fig. 2). The precise depth to which the Stage II foundation soils required stabilization was established early during construction based on an extensive Standard Penetration Testing (SPT) program.

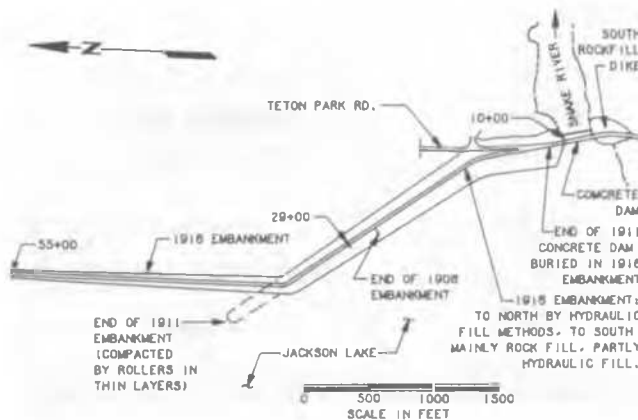


Figure 1. Schematic Plan View of Jackson Lake Dam (Modified from Lockhart et al, 1986)

STABILIZATION ALTERNATIVES

The USBR Stage II bid documents allowed four stabilization methods which could be used alone or in combination: excavation and replacement, compaction piles, jet grouting, and dynamic compaction which could only be used to a maximum depth of 30 feet. However, the offerors were also allowed to propose variations to these methods provided that detailed data and case histories could be presented to demonstrate that the variations would achieve the required results.

An evaluation was made of the specified methods with emphasis on cost and constructibility. This study suggested that densification of deep treatment areas by compaction piles was likely to be unfeasible within the required schedule. Jet grouting and dynamic compaction were both considered technically feasible and economically

competitive, although the latter could only be used to densify shallow treatment areas. The excavation and replacement alternative entailed a serious ground-water control problem. The hydrogeology of the interfingering foundation soils was not fully characterized, so the cost of dewatering was uncertain. Conservative assumptions on the permeability and extent of water-bearing soils made this alternative economically unattractive.

In addition to the specified alternatives, several bidders proposed other stabilization methods. The most attractive one, which was eventually accepted, is a soil stabilization technique developed in Japan called Soil Mixing Wall (SMW). The accepted dam cross-section configuration, shown on Fig. 2, included two zones of SMW-stabilized soils under the upstream and downstream shells of the dam and a cutoff wall to be constructed using the same technique. The approximately 130-foot-wide center area of the foundation between the two SMW-stabilized zones would be densified by dynamic compaction. The SMW-stabilized zones would provide containment for the potentially liquefiable soils below the depth effectively treated by dynamic compaction.

SMW WORK

The SMW technique involves using multiple-shaft mixing auger machines (Fig. 3) to drill 3-foot-diameter columns through the foundation soil. During drilling, the in-situ soil is mixed with cement-bentonite-water grout which is pumped through ports at the bottom of the auger shafts. The shafts have cutting and mixing blades and are physically linked together with tie-bands to prevent gaps at joints between columns.

At Jackson Lake Dam, both two-auger and three-auger machines were used. The two-auger machines, used for soil stabilization, made two-column panels with each column tangent to adjacent columns (Fig. 4-A). Panels were installed consecutively, with one column of each panel completely overlapping the last column of the previous panel.

The three-auger machine, equipped with 34-inch-diameter overlapping augers, was used primarily for cut-off wall construction. The three-column panels had a minimum width of 24 inches at the overlap section, assuring wall continuity (Fig. 4-B). Installation proceeded by drilling



Figure 3. SMW Two-Auger Machines

alternate "primary" panels followed by interspersed "secondary" panels. Each end column of the secondary panels completely overlapped the end column of the adjacent primary panel.

Prior to column installation, a shallow trench was constructed at the column location to contain excess soil-grout mixture. Steel templates were installed along the edge of the trench and aligned to accurately locate each column. Once the machine was moved into the correct position, verticality of the shafts was checked using sensors installed on the machine. Drilling was then begun, with the augers moving down slowly to the predetermined depth and then withdrawing. Grout was injected and mixed with the soil during both penetration and withdrawal of the augers.

The SMW columns were installed to form honeycomb grids in two 50-foot-wide zones along the upstream and downstream toes of the dam (Fig. 2 and 5). As shown on Fig. 5, the cutoff wall forms the upstream boundary for the upstream grid. The grid pattern was designed by the USBR to achieve the required foundation shear strength and to provide containment of potentially liquefiable soils in the foundation, thereby minimizing embankment deformation. Key SMW construction dimensions and productivity data are summarized on Table I.

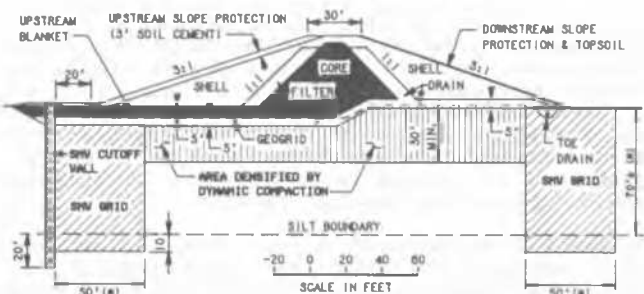


Figure 2. Typical Cross-Section Configuration

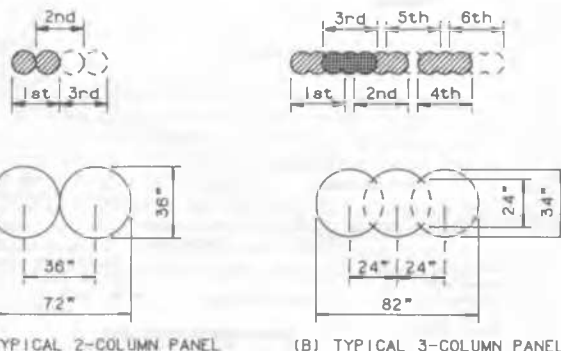


Figure 4. SMW Panel Dimensions and Installation Sequence

TABLE I
SMW Construction Dimensions and Average
Production Rates at Jackson Lake Dam

	Cutoff Wall	Soil Stabilization Grid
Total Quantity (Ft ²)	205,500	1,315,725
Maximum Depth	109	100
Average Productivity per 12-hr. Shift*:		
For a Column Depth of (Ft)	50	99
Panels (Each)	15	7
Wall Surface (Ft ²)	3,100	2,080

*April-May 1988

Project specifications required the soil-grout mix (soilcrete) to have a minimum shear strength of 200 pounds per square inch. The quality control program included sampling and testing of one SMW column from each day's production. Wet mix samples were recovered from two depths (typically 20 and 40 feet) using an inflatable packer sampler especially developed for the project. Sampling was performed immediately after column completion. The samples were cured in molds for 7, 28, 56 and 112 days under controlled moisture and temperature conditions and were broken in unconfined compression and triaxial compression tests. Additionally, the USBR cored some of the hardened columns and conducted strength tests on the core samples.

While strength data are still being gathered as the project progresses, a preliminary review of the data available on March 1988 leads to the following conclusions:

- Soilcrete strength is highly time dependent, with 112-day strengths being about 60 percent greater than 28-day strengths (Fig. 6). Further strength gains with age are anticipated.
- While the in-situ soils grade from coarser to finer with depth (gravels near the surface, sands in the middle of the treated area and silts at the bottom), preliminary

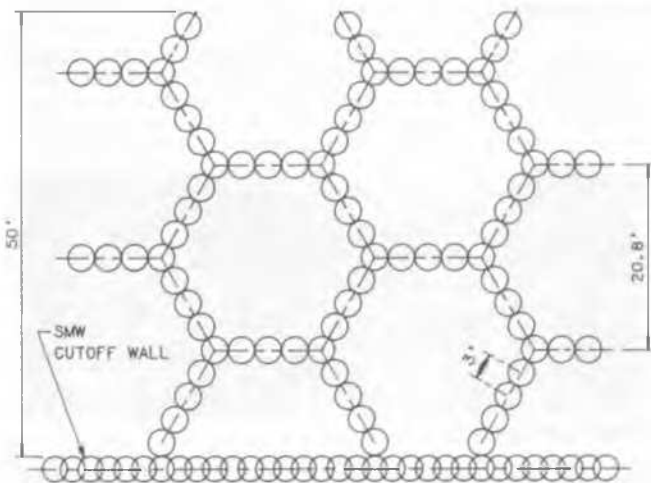


Figure 5. Plan of SMW Grid Pattern for Upstream Treatment Area

strength results do not show decreasing strengths with depth. This suggests that good mixing of the soils is being achieved throughout the length of the columns, resulting in a relatively homogeneous soilcrete material.

- Soilcrete strengths measured by tests on samples cured in the laboratory are typically lower than the strengths measured by tests on core samples. The differences probably result from unrepresentative sampling and different field and laboratory curing conditions (e.g., confining pressure, moisture and temperature).
- Current procedures for wet mix sampling and laboratory curing result in highly conservative, and rather coarse, estimates of the in-situ soilcrete strength. Sampling of the field-cured material by coring the hardened columns provides better results but is expensive and complicates scheduling.

Strength test results were used during the work to evaluate and modify the soilcrete mix design. The water/cement ratio of the mix was decreased from an initial 1.35 to 1.25, and the cement content was decreased from over 800 pounds per cubic yard of soilcrete to about 590 pounds per cubic yard. Bentonite in the amount of 8 pounds per cubic yard was also added to the mix to improve workability.

Because Jackson Lake Dam is located within a U.S. National Park in an area of pristine beauty, environmental concerns were of critical importance. In the SMW method the soil is never removed from the hole and there are no open excavations, so the possibility of sudden loss of slurry and trench collapse, always present in conventional slurry cutoff wall construction, is eliminated. Good control of mixing fluids (grout or slurry) is a significant advantage in environmentally sensitive sites such as Jackson Lake Dam.

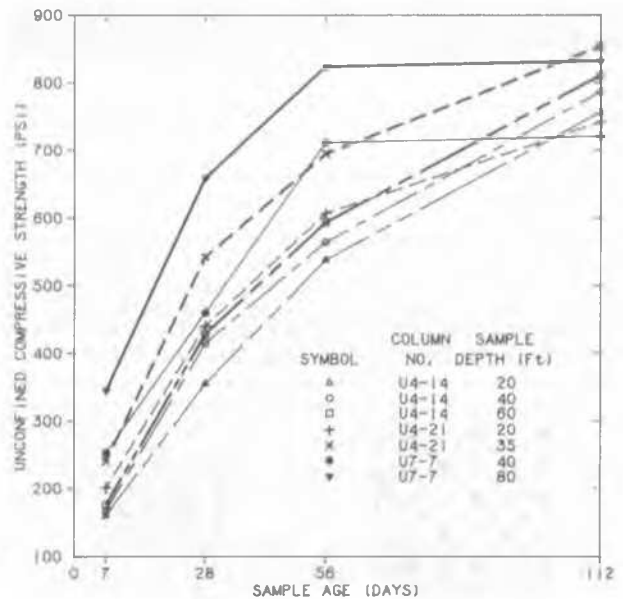


Figure 6. Typical Unconfined Compressive Strengths of Laboratory-Cured Soilcrete Samples

DYNAMIC COMPACTION

Dynamic compaction was used to densify the Stage I foundation between Stations 29+00 and 52+00 and the shallow treatment area of the Stage II foundation (Fig. 2) south of Station 29+00. The dynamic compaction program and grid pattern are presented on Table II and Fig. 7, respectively. The compactive effort consisted of three heavy tamping phases followed by an ironing phase.

TABLE II
As-Constructed Dynamic Compaction Program

Impact Points	Weight (Tons)	Drop Height (Ft)	Number of Drops
Primary	32	100+	20
Secondary	32	100+	15
Tertiary	32	100+	10
Ironing	32	31	2

At each primary point, ten consecutive weight drops were made, after which the resulting crater was backfilled with granular soil dumped from trucks and smoothed out with a front end loader. Then the remaining ten drops were made and the crater was backfilled again. Typically the craters had 6- to 8-foot depths and 8- to 12-foot diameters. Drops at the secondary impact points resulted in craters with depths of 5 to 7 feet. Tertiary drops caused crater depths of 3 to 6 feet. The ironing phase consisted of a blanket coverage of the downstream portion of the foundation to densify the uppermost soils. Drop spacing was 6 feet, equal to the drop weight width. In total, 54,298 heavy tamping drops and 21,294 ironing drops were made.

Foundation drainage was provided by 10- to 15-foot-deep drainage trenches along the embankment perimeter. The drainage trenches maintained the ground-water level below the bottom of the craters.

Dissipation of the excess pore-water pressures generated by the compaction effort was facilitated by vertical drainage wicks installed at 5-foot centers. The wicks extended through localized fine-grained layers which would have impeded dissipation of excess pore pressures from the soils within and below these layers. Wick depths ranged from about 20 to 35 feet. Total installed wick length was about 413,000 ft.

Evaluation of the effects of dynamic compaction was performed by the USBR based on the results of pre- and post-compaction SPT sampling programs. SPT boreholes were drilled on approximately 50-foot centers before and after dynamic compaction. Measured blow counts were normalized for over-



Figure 7. Typical Dynamic Compaction Grid Pattern

burden pressure, rod energy delivery and soil fines content. Pre- and post-compaction blow counts were compared for selected matched soil intervals (Von Thun, 1988).

The average SPT blow count increases resulting from dynamic compaction are summarized on Table III. As anticipated, greater densification resulted for coarse-grained soils than for fine-grained soils. Also, the Stage II work had a greater effect than Stage I work. Von Thun (1988) attributes this to better drainage of the foundation material during Stage II through (1) greater use of wick drains, (2) deeper perimeter drainage trenches, and (3) longer cycle time between drops (90 seconds for Stage II versus 60 seconds for Stage I). The depth of recognizable effect of treatment, based on the SPT investigations, generally reached at least 30 feet for Stage I and 40 feet for Stage II.

TABLE III
Average Increase in SPT Blow Count by Soil Type
(Modified from Von Thun, 1988)

Stage	Station	Soil Type			
		GP and SP	SM	ML	All Soils
I	29+00 - 52+00	14	10	6	10
II	12+00 - 29+00	54	22	16	26

CONCLUDING REMARKS

At Jackson Lake Dam, a highly seismic site, dynamic compaction and the SMW technique were successfully used to stabilize the loose alluvial materials in the dam foundation and minimize liquefaction potential. This project is the first U.S. application of the SMW technique, an innovative ground improvement technology of wide use in Japan, and it is an example of successful construction activities in an environmentally sensitive site such as the Grand Teton National Park.

REFERENCES

- Lockhart, A.C., Link, R.A. & Buehler, J.B. (1986). Geologic Report for Final Design, Jackson Lake Dam Modification, Minidoka Project, Wyoming. U.S. Dept. of the Interior, Bureau of Reclamation, Pacific Northwest Region, Boise, Idaho.
- Von Thun, J. L. (1988). Preliminary Results of Dynamic Compaction Stage I and Stage II Treatment of Jackson Lake Dam Foundation. USCOLD Newsletter No. 85, 14-18.
- Welsh, R. H., Luebke, T. A. and Collins, M. J. (1987). An Overview of Jackson Lake Dam Modifications. USCOLD Newsletter No. 84, 1-9.

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