Presented at the November 2008 IA Technical Conference. Anaheim, CA.
http://www.itrc.org/papers/ia/canal.pdf ITRC Paper No. P08-002

Canal Seepage Reduction by Soil Compaction

Presented to the IA Technical Conference, Anaheim, CA. Nov. 2008

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Abstract. *Large-scale tests were conducted of in-place compaction of irrigation district earthen canal bottoms and sides. Five canal pools with sandy loam soils were compacted. Seepage reduction of about 86% was obtained when the sides and bottoms were compacted; reductions of 12 – 31% were obtained when only sides were compacted.*

Keywords. irrigation, canal, compaction, seepage, irrigation district

Introduction

Irrigation districts that rely upon long, open canals share a common problem: canal seepage. Canal seepage can create difficulties including:

- Reduced water deliveries to farmers
- Increased pumping costs if the water in the canals is lifted by pumps
- Increased drainage problems, possibly causing crop yield and health problems
- Loss of water supply in a basin if the seepage goes to a salty aquifer or into the ocean
- Increased diversion from rivers, resulting in decreased in-stream flows

The two most common solutions for reducing seepage are lining canals or replacing them with pipes. These options bring along with them additional benefits, such as stabilization of banks (canal lining) or reduced need for access and fewer drownings (pipelines). However, these solutions are expensive. A typical piping cost in California for an irrigation district is in the neighborhood of $120 - $200/foot for pipe sizes in the 4' – 5' range (flows in the 20 – 30 CFS range). Canal lining costs are often in the neighborhood of $1 million per mile, which is prohibitive for most irrigation districts.

Therefore, the Irrigation Training and Research Center (ITRC), with support from CALFED and the California Agricultural Research Initiative, has experimented with an uncommon method of seepage reduction – in-place compaction of canal banks and canal bottoms.

Concepts of Soil Compaction

The general concepts of soil compaction for seepage reduction and soil consolidation are well documented in civil engineering, under the category of "soil mechanics". Everyone is familiar with compaction of soils for roadways, even if they do not understand the technical details. Additionally, many people are aware that two of the major dams in California (Oroville Dam and San Luis Dam) are earth-filled dams rather than concrete structures.

Soil laboratory tests for compaction (Proctor and Modified Proctor) have specified procedures by ASTM. Samples of soil are compacted by specified layer thicknesses, by specified weights dropped a specified number of times from a specified height. In a compaction test, this is typically done with a number of samples, each of a different moisture content. A graph such as Figure 1 is developed, illustrating what the moisture content should be during construction.

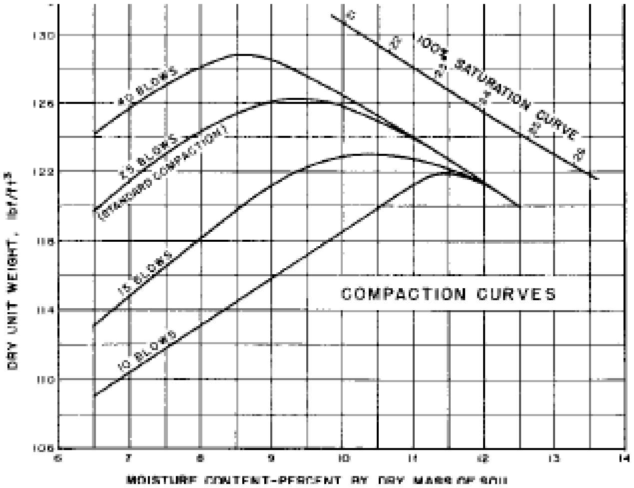

Figure 1.   Compaction curves (USBR, 1998)

It is relatively common knowledge that some soils compact better than others and that as the level of compaction increases, the soil hydraulic conductivity (seepage rate) decreases. Optimum compaction will also depend upon the moisture content during compaction. If the soil is too moist or too dry, it will not achieve the "optimum bulk density". Different compaction techniques are suited for one soil or another, as shown in Table 1.

Table 1. Compaction equipment (Bader, 2001)

Effect of Soil Type on Equipment selection				
		Vibrating Sheepsfoot Rammer	**Static Sheepsfoot Smooth Roller**	**Vibrating Plate Vibrating Roller**
	Lift Thickness	*Impact*	*Pressure*	*Vibration*
Gravel	12 in.	Poor	No	Good
Sand	10 in.	Poor	No	Excellent
Silt	6 in.	Good	Good	Poor
Clay	6 in.	Excellent	Very Good	No

Additionally, the optimum moisture content for high bulk density does not necessarily translate to the optimum moisture content for reduced seepage. There are differences between laboratory and field activities and results. Some engineers believe that a slightly-moister-than-"optimum" soil in the field provides the best seepage reduction.

Soil Compaction for Sealing Canals

Perhaps the best source for information on earth lining of canals is a publication by ANCID (Australian National Committee on Irrigation and Drainage, 2001) entitled "Open Channel Seepage and Control". This publication, as well as others, focuses on bringing soil material to the site one layer at a time and compacting each layer. The publication does mention "in situ" compaction – which is in-place compaction of existing canal banks and bottoms. The senior author has talked to engineers from dozens of irrigation districts in California about this, and has not encountered anyone who has tried it before this experiment.

Field Experiments in California

ITRC contacted four irrigation districts in the San Joaquin Valley of California who were experiencing seepage problems:

- Panoche WD
- Chowchilla WD
- San Luis Canal Co (also known as Henry Miller Reclamation District)
- James ID

Seepage tests were conducted on two Panoche WD canals, and it was determined that the seepage rates were very low. Plus, the soil was a heavy silty clay loam and it would have been impossible to dry the soil out enough for compaction without just making mud.

The other three districts had sandier soil, so compaction trials were conducted there. The results of one canal compaction effort in Chowchilla cannot be reported because the well that would have supplied the water for post-compaction seepage tests failed and was not repaired.

All the compaction work was "in-situ", meaning that there was no addition of soil, and no over-excavation and replacement of compacted soil layers. The compaction was performed on the soil surface "as-is" with the exception of some smoothing of canal banks.

Seepage Tests. Prior to, and after compaction, ponding tests were conducted to determine the seepage rates. The ponding tests involved the following:

- The entire canal pool that was compacted was filled with water to the normal operating depth.
- The ends of the pool were sealed to prevent water from entering or leaving the pool.
- Weather data was recorded from the nearest CIMIS station, to estimate evaporation losses.
- Redundant water level sensors were installed to measure the change in water depth versus time.
- The water was replenished occasionally with a metered supply to maintain a fairly constant water level.
- Water temperatures were measured, to correct for different viscosities in pre- and post-compaction tests.
- Measurements began after water had been standing in the pool for several days, and continued for 1-3 days.

Figure 2. James ID Main Canal during pre-compaction seepage test.

Figure 3. James ID Main Canal during side compaction

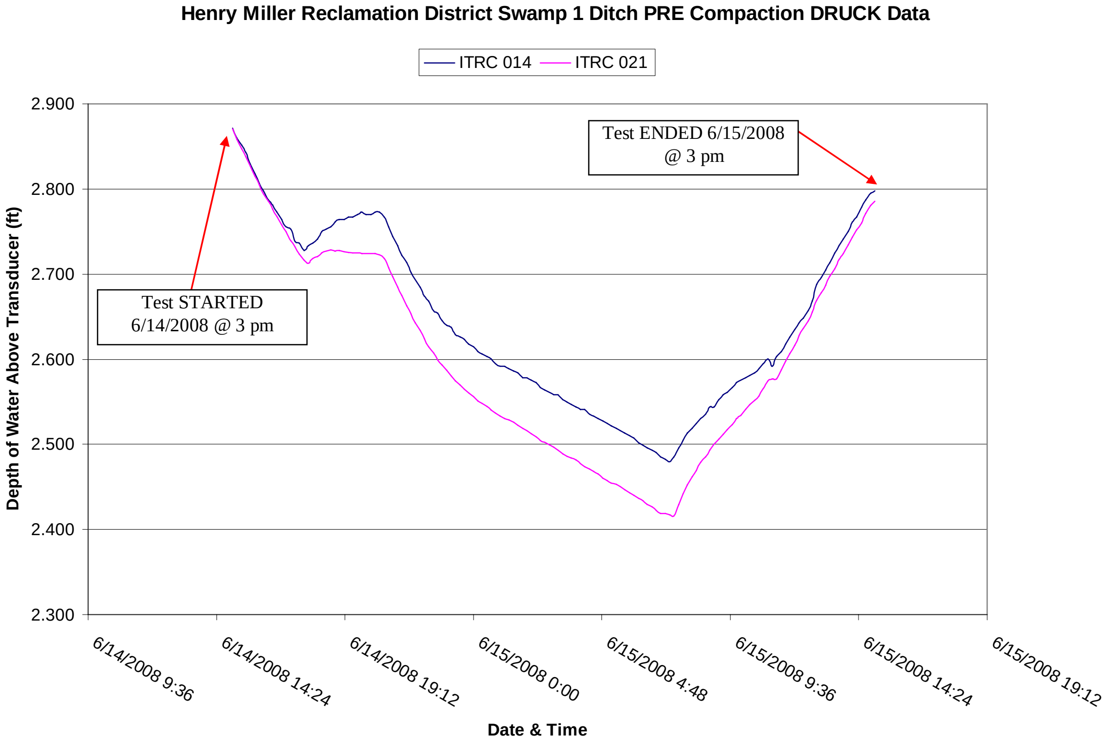

Figure 4. Pressure transducer data for ponding test – San Luis Canal Co (Henry Miller RD)

Soil Preparation. During the first compaction work at Lateral H in James ID, it was learned that if the canal banks were smoothed off, the compactor could operate much more quickly. Subsequent locations were therefore lightly smoothed off. There was no opportunity to obtain the "optimum" moisture content for compaction. Field conditions and availability required that the compactor begin work as soon as the canal had dried down enough to use the equipment without making mud. Certainly, moisture contents were different at various depths in the bands and bottom.

Laboratory Tests. Soil samples were taken in the field for a number of reasons. In some cases, undisturbed core samples were taken to measure bulk density before and after compaction. Texture samples (about 20 per canal section) were taken at various depths. Laboratory experiments were run with the modified Proctor test to determine optimum moisture contents for compaction, and the effects on hydraulic conductivity. Those laboratory results and their correlations with the field results have not yet been completed.

Equipment and Costs. The soil was compacted using a 45-thousand pound Kobelco excavator with an MBW 36-inch roller attached to the end of the boom. Installed immediately between the UVW-36 roller and the end of the excavator boom was a UV-10K exciter. This exciter is a hydraulically driven vibration mechanism. Since the vibratory exciter was hydraulically driven, the excavator operator could engage and disengage the exciter when he felt it was necessary.

The compaction accessories cost about $25,000 (not including the cost of the excavator) installed. An experienced operator was able to compact the sides of 1 mile of canal (both sides, meaning 2 miles total) in about 8 days. The cost for the operator, transport of the excavator, and the excavator rental was about $1.20/foot of canal, with about 10 feet of compaction on each side of the canal (cost = $1200 for 1000' long pool).

Figure 5. MBW 36" vibratory roller attached to the end of an excavator arm.

Figure 6. Compacting the sides and bottom of Lateral H at James ID

Figure 7. Compacting the canal banks on the James ID main canal with an MBW vibratory roller

Results

Table 2 shows the results of the in-situ compaction. Seepage reduction varied from 12% to 89%. Clearly, the three sites at which the canal bottom was compacted had much better results than the two sites at which only the sides were compacted. The seepage differences were probably due to additional factors, but this appears to be one possible explanation.

Table 2. Compaction results

Irrigation District	Location	Compaction		Cost, $	L, ft	Canal width, ft	Texture	Pre-Seepage, GPM	Post-Seepage, GPM	% Seepage Reduction
		Sides	Bottom							
Chowchilla WD	Site #2 – Ash Main Canal, between roads 11-12	Y	N	4,845	4,240	27	Loamy Sand	143	126	12*
James ID	Lateral H, from Main Canal to TO	Y	Y	3,240	1,010	15	Sandy Loam	86	12	86
James ID	Main Canal	Y	N	15,800	10,238	58	Sandy Loam	252	173	31
San Luis Canal Co.	Swamp 1 Ditch, between Turner Island & Deep Well	Y	Y	1,945	1,730	27	Sandy Loam	130	14	89
San Luis Canal Co.	East Delta Canal	Y	Y – with ride-on	3,100	3,020	19	Loam	80	8	90

*The Chowchilla WD site had sections of rip-rap along the canal banks that could not be compacted, resulting in a lower % seepage reduction

Conclusion

For sandy loam soils, in-situ compaction with a vibratory roller reduced seepage. The seepage reduction was significant (86 – 89%) when both the sides and bottom were compacted. The compaction extended to a depth of about 2 feet, so it is suspected that the seepage reduction will withstand normal maintenance activities from year to year.

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