that the local material had peculiarities of its own, and that it was no doubt quite different physically from the material tested by Bell and Goodrich.

The writer will not attempt to discuss this matter further, but suggests it as a fruitful topic for further experiment.

Experiments were made by Mr. Hawley with various local materials at various pressures. These showed that, with low pressures, the coefficient of friction was distinctly larger than it was with higher ones. The explanation for this may be that the higher pressures broke down and crushed the particles, and so reduced the relative resistance. After a certain pressure was reached there was less rapid change in the coefficients, and for the higher pressures the coefficients for any material were practically constant.

For material from the local soft sandstone rocks at San Pablo, coefficients of friction of approximately 0.5 were found.

There was one kind of material more slippery than the others for which an average coefficient of 0.45 was found. Other harder materials gave coefficients of 0.55 and more. Sand and gravel from the creek representing the remnants of much harder rocks in the hills (and so corresponding more nearly to the glacial drift of the eastern states) gave coefficients of about 0.7.

The materials at San Pablo are similar to the materials at Calaveras; and there is reason to think that the coefficients found at San Pablo would apply approximately to the Calaveras materials.

What then is the explanation of the fact that the Calaveras Dam slip indicated a coefficient of 0.2 while similar materials in the test apparatus show a coefficient of 0.5—two and one-half times as much?

The answer seems to lie in the fact that in the course of construction at Calaveras, before the dam was very high, the construction pool in the centre of the dam was sometimes quite wide; so that at some levels the greater part of the width of the dam was composed of fine-grained core material. Afterward the proportion of solid fill was increased and the width of core reduced, but the effects of the wide pool may have been permanently left in layers of core material extending far out under the more solid parts of the toes.

It seems probable that unstable core material placed in this way furnished the lubricant that facilitated and made possible the slip in the dam.

Section of Dam Required

Regarding the section of dam required with the core material considered as a fluid: At Calaveras, the toe material was slightly heavier per cubic foot than the core material. At San Pablo, with fragments of porous sandstone rock predominating in the toes, there was scarcely any difference. With harder material like the glacial drift of the Eastern States, the toe material would be considerably heavier.

For the purpose of a first rough calculation, assume that the weights per cubic foot of toe and core material are equal, as they are at San Pablo. If a coefficient of friction of 0.5 is assumed, each toe must weigh twice as much as the pressure exerted by the core. The pressure exerted by the core is ½ wh^2 and the weight of the toe to balance it must be wh^2. To produce this weight, a uniform outer slope of 2 to 1 will suffice. In addition, a top width equal to the maximum width of core must be used. If a factor of safety of 2 is required, the outside slope must be made 4 to 1, but in view of the records of slips in actual dams, it may well take a higher factor of safety. A slope of 5 to 1 will give a factor of safety of 2.5 and a slope of 6 to 1 will give a factor of 3. Where toe material is considerably heavier than the core, as would be the case with harder and heavier rocks, the slopes could be reduced in proportion to the increased specific gravity without reducing the factor of safety. Thus, with toe material 20% heavier than core material, a slope of 1 to 5 would allow a factor of safety of 3. Very few hydraulic dams have been built with sections as large as this line of thought suggests. The Gatun Dam at Panama heads the list, and is even larger.

TABLE 2—DIMENSIONS OF A NUMBER OF EARTH DAMS THAT HAVE STOOD SUCCESSFULLY

Dam	Height to Flow Line, H	Area of Section in Sq. Ft., A	Ratio, $\frac{A}{H^2}$	Free-board	Width in Feet: Top	At Flow Line	50 Feet Below Flow Line	100 Feet Below Flow Line	Bottom, W	Ratio, $\frac{W}{H}$
*Gatun	78	99,200	16.30	30	100	397	1,469	...	1,990	25.5
*Big Meadows	64	24,300	5.93	20	30	160	460	...	548	8.56
*Coquitlam ..	83	38,700	5.61	15	40	145	521	...	702	8.48
*Cambria	82	31,200	4.65	13	20	98	429	...	685	8.34
Ashokan	90	35,400	4.37	20	34	112	400	...	650	7.23
Druid Lake ..	82	27,900	4.15	5	60	90	390	...	582	7.10
San Andreas ..	80	26,200	4.10	5	30	58	387	...	606	7.58
*Paddy Creek .	120	58,200	4.05	25	23	161	414	664	757	6.30
*Somerset ...	92	33,200	3.94	13	25	78	375	...	616	6.67
San Leandro .	65	16,350	3.88	5	30	56	335	...	457	7.04
*Haiwee	75	21,600	3.85	14	20	90	340	...	465	6.20
Croton	96	33,400	3.62	24	30	126	336	...	528	5.50
Tabeaud	86	26,400	3.57	8	20	60	345	...	553	6.44
*Necaxa	164	90,800	3.36	16	54	136	386	636	954	5.81
Cold Spring ..	88.5	26,200	3.34	10	20	70	320	...	512	5.79
Belle Fourche	100	33,100	3.31	15	20	65	284	656	656	6.56
Lahontan	112	40,900	3.25	12	20	80	330	580	640	5.72
Santa Maria ..	85	23,500	3.25	8	20	60	310	...	485	5.71
Pilarcitos	74	17,600	3.22	5	30	56	288	...	415	5.61
Morris	90	25,700	3.18	9	20	60	309	...	502	5.58
Borden Brook	64	12,700	3.10	7	24	49	280	...	337	5.27
Honey Lake ..	90	25,000	3.08	6	20	50	300	...	500	5.56
Goose Creek ..	137.5	54,900	2.90	7	16	54	304	554	741	5.39

*Hydraulic fill, wholly or in large part.

A great many cubic yards are involved in such a large section, but if the work is done cheaply enough per cubic yard, it may be economical to use the extra volume. Safety can be secured in this way; and it may be that this procedure is the best one to follow.

Dimensions of Several Dams

To see what these slopes would call for in the way of section in comparison with earth dams that have been actually built either by the hydraulic method or as dry fill, the following comparison is made. Assuming a freeboard of one-tenth the greatest depth of water, H, and a top width of 0.25 H and uniform slopes, the cross-sections of dams in terms of the greatest depth of water would be as follows:—

Slope.	Volume.
3 to 1	$3.9\,H^2$
4 to 1	$5.1\,H^2$
5 to 1	$6.3\,H^2$
6 to 1	$7.5\,H^2$

The actual dimensions of a number of dams are given in Table 2.

Rock-fill dams are not included, but rock fill forms some part of a number of dams in the list. No dams holding less than 64 ft. of water are included.