2 — G. NOGUERA *(Expert)*

A — Introduction

In contrast to embankment dams with a central impervious core, the CFRD (Concrete Face Rockfill Dam) is very sensitive to the settlement and deformation of the rockfill supporting the upstream face. These deformations produce movements of the concrete slab joints, opening them, and if the movements exceed certain limits the resulting leakage is difficult to control.

The above leads to the conclusion that an initial evaluation of deformations, adjusted to actual conditions, may require modifications to the design, modifications to the joints, and even a change from a concrete face to a much more deformable bituminous face material.

B — Stress-strain in embankment dams

M. D. Fitzpatrick and his Australian colleagues have measured rock modulus in rockfill dams and have arrived to the following conclusions :

E_{rc} = modulus of deformation of rockfill during construction.

E_{rf} = modulus of deformation of rockfill during reservoir filling.

δ_v = maximum crest settlement.

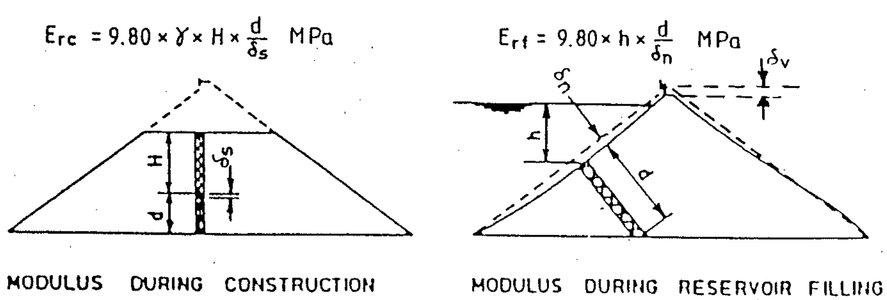

Fig. 1

Determination of Rockfill Modulus.

$E_{rf}/E_{rc} = 2.2.$ as an average.

This ratio may vary between 1.5 and 3.3.

On the other hand J. A. Charles and A. D. M. Penman from Great Britain in Report 38 of Question 61 has derived simple empirical relationships for estimating maximum settlement during construction, maxi-

mum normal deflection of the upstream membrane measured during first filling, and maximum horizontal movement of central core measured during first filling.

These relationships are the following :

— Maximum settlement during construction :

$$S_{max} = 0.3\ \gamma\ H^2/D^*$$

in which :

γ = unit weight of rock or gravel fill

H = embankment height

D* = Constrained modulus of rock or gravel fill (measured in an oedometer) similar to E_{rc} defined previously.

— Maximum normal deflection of the upstream membrane measured during first filling :

$$N_{max} = 0.25\ S_{max}$$

— Maximum horizontal movement of the central core measured during first filling :

$$H_{max} = 0.40\ S_{max}$$

These relations are the results of different measurements in dams shown in Fig. 2.

Therefore, in static conditions it is relativily simple to obtain, in an approximate manner, the deformations that the upstream membrane will experience.

C - Deformations in the dynamic condition

The deformations for dynamic loading are somewhat more difficult to evaluate but some advances have been realized.

In the proceedings of the Symposium sponsored by the Geotechnical Engineering Division of the ASCE, in their Detroit, Michigan Convention in October 1985, dedicated to " Concrete Rockfill Dams, Design Construction and Performance ", the article " Seismic Analysis of Concrete Face Rockfill Dams " by G. Bureau, R. L. Volpe, W. H. Roth and T. Udaka presented Fig. 3,relates the Earthquake Severity Index (ESI) with relative vertical settlement.

The Earthquake Severity Index has been defined as :

$$ESI = PGA\ (M - 4.5)^3$$

in which :

PGA = Peak Ground Acceleration

M = Ritchter magnitude

Fig. 3 is based on Table 1.

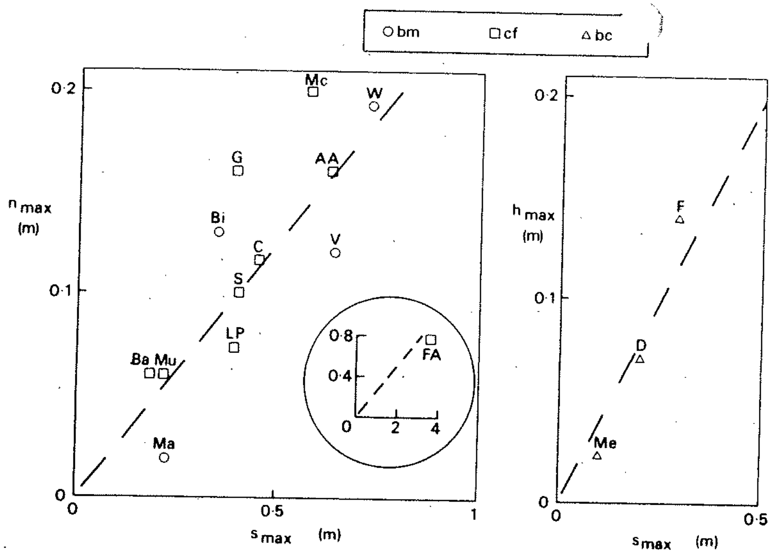

Fig. 2

Maximum deflection of membranes and cores during first filling of reservoir related to constructional settlement

Flèches maximales des masques et des noyaux pendant le premier remplissage de la retenue en fonction du tassement de construction

(s_{max})	Maximum settlement measured during construction	*(s_{max})*	*Tassement maximal mesuré pendant la construction*
(n_{max})	Maximum normal deflection of upstream membrane measured during first filling	*(n_{max})*	*Flèche normale maximale du masque amont mesurée au cours du premier remplissage*
(h_{max})	Maximum horizontal movement of central core measured during first filling	*(h_{max})*	*Mouvement horizontal maximal du noyau central mesuré pendant le premier remplissage*
(bm)	Bituminous upstream membrane	*(bm)*	*Masque amont en béton bitumineux*
(bc)	Bituminous central core	*(bc)*	*Noyau central en béton bitumineux*
(cf)	Concrete faced	*(cf)*	*Masque en béton*
(AA)	Alto Anchicaya	*(AA)*	*Alto Anchicaya*
(Ba)	Bastyan	*(Ba)*	*Bastyan*
(Bi)	Bigge	*(Bi)*	*Bigge*
(C)	Cethana	*(C)*	*Cethana*
(D)	Dhunn	*(D)*	*Dhunn*
(F)	Finstertal	*(F)*	*Finstertal*
(FA)	Foz do Areia	*(FA)*	*Foz do Areia*
(Ma)	Marchlyn	*(Ma)*	*Marchlyn*
(G)	Golillas	*(G)*	*Golillas*
(LP)	Little Para	*(LP)*	*Little Para*
(Mc)	Mackintosh	*(Mc)*	*Mackintosh*
(Me)	Megget	*(Me)*	*Megget*
(Mu)	Murchison	*(Mu)*	*Murchison*
(S)	Salvajina	*(S)*	*Salvajina*
(V)	Venemo	*(V)*	*Venemo*
(W)	Winscar	*(W)*	*Winscar*

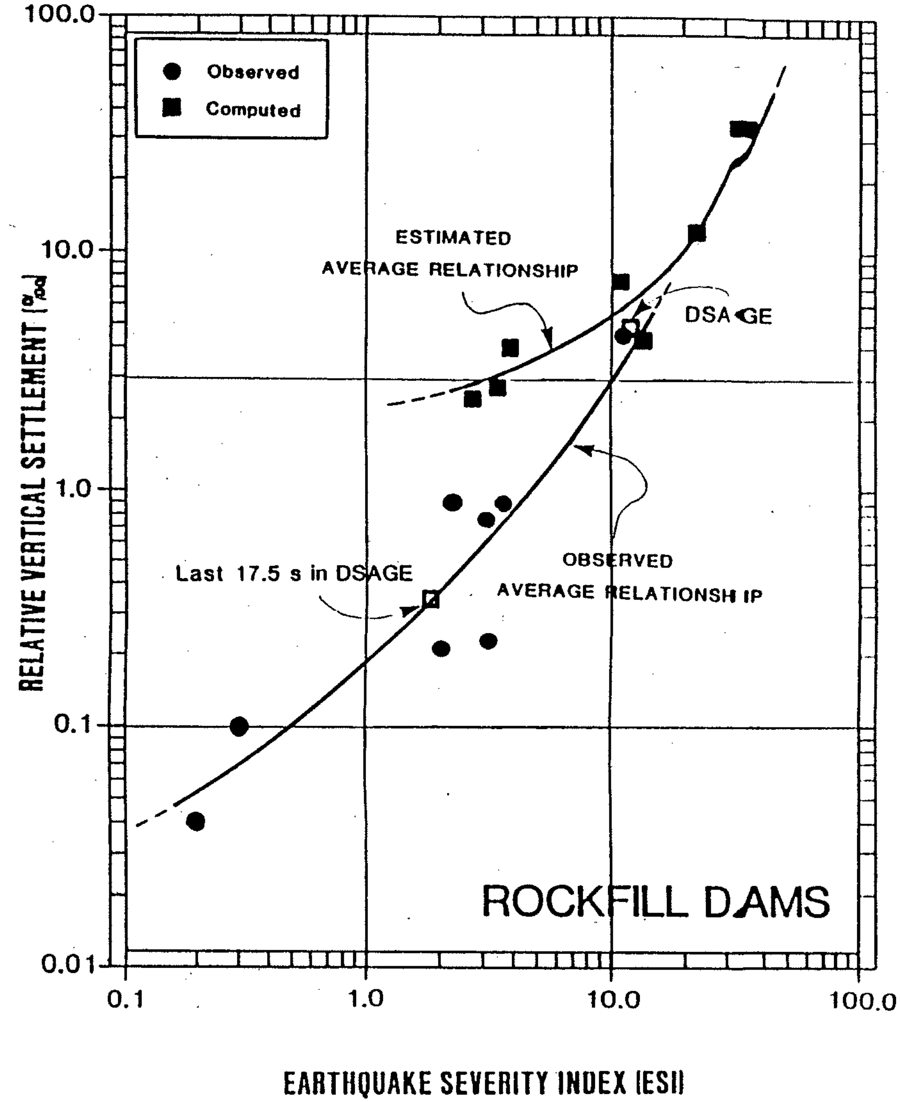

Fig. 3

Relationship Between Crest Settlement and ESI

DAM NAME (location)	H (m)	△H (mm)	RELATIVE SETTLEMENT (°/oo)	PGA (g)	M	ESI	REFERENCE
COGOTI (Chile)	84	381(o)	4.54	0.20	8.3	11.0	(41)
MIBORO (Japan)	131	30(o)	0.23	0.20	7.0	3.1	(29),(41)
MINASE (Japan)	67	7(e) 61(o)	0.10 0.91	0.02 0.08	6.9 7.5	0.3 2.2	(27)
OROVILLE (Calif.)	235	9(o)	0.04	0.10	5.7	0.2	(46)
EL INFIERNILLO (Mex.)	148	130(o)	0.88	0.12	7.6	3.6	(35)
LA VILLITA (Mex.)	60	45(o)	0.75	0.10	7.6	3.0	(35)
LEROY ANDERSON (Calif.)	72	15(o)	0.21	0.41	6.2	2.0	(44)
TERROR LAKE (AK)	50	600(e)	12.00	0.35	8.5	22.4	(18)
TERROR LAKE (AK)	50	300(e)	4.00	0.50	6.5	4.0	(18)
CIRRATA (Indonesia)	125	300(e)	2.40	0.35	6.5	2.8	(18)
PUEBLO VIEJO (Guatemala)	133.5	4450(e)	33.33	0.65	8.25	34.3	(4)
CHICOASEN (Mexico)	240	1000(e)	4.17	0.95	7.0	13.3	(13)
FORTUNA (Panama) (raised)	104	800(e)	7.69	0.40	7.5	10.8	(16)
USBR (Example Dam)	213	700(e)	2.72	0.43	6.5	3.5	(45)
Dames & Moore (Example Dam)	100	487(e)	4.87	0.70	7.1	12.3	DSAGE (This paper)

) observed
) estimated

Table 1

Relative Settlement and ESI Data

The authors note that a relationship between ESI and relative settle-ent seems apparent.

The correlation presented resulted in a lively discussion and in the osure comment by the authors data from La Villita and Infiernillo Dams Mexico were added (Fig. 4). They also pointed out future directions

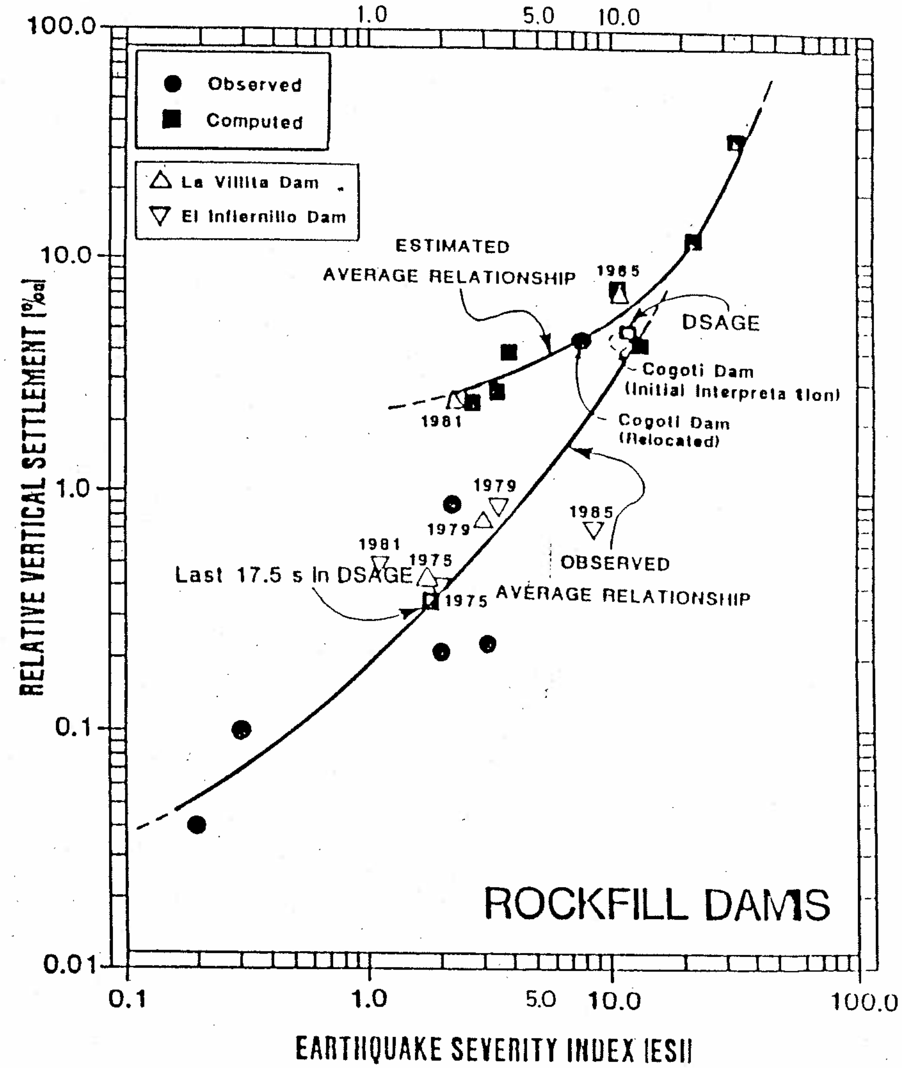

Fig. 4

Relationship between Crest Settlement and *ESI*

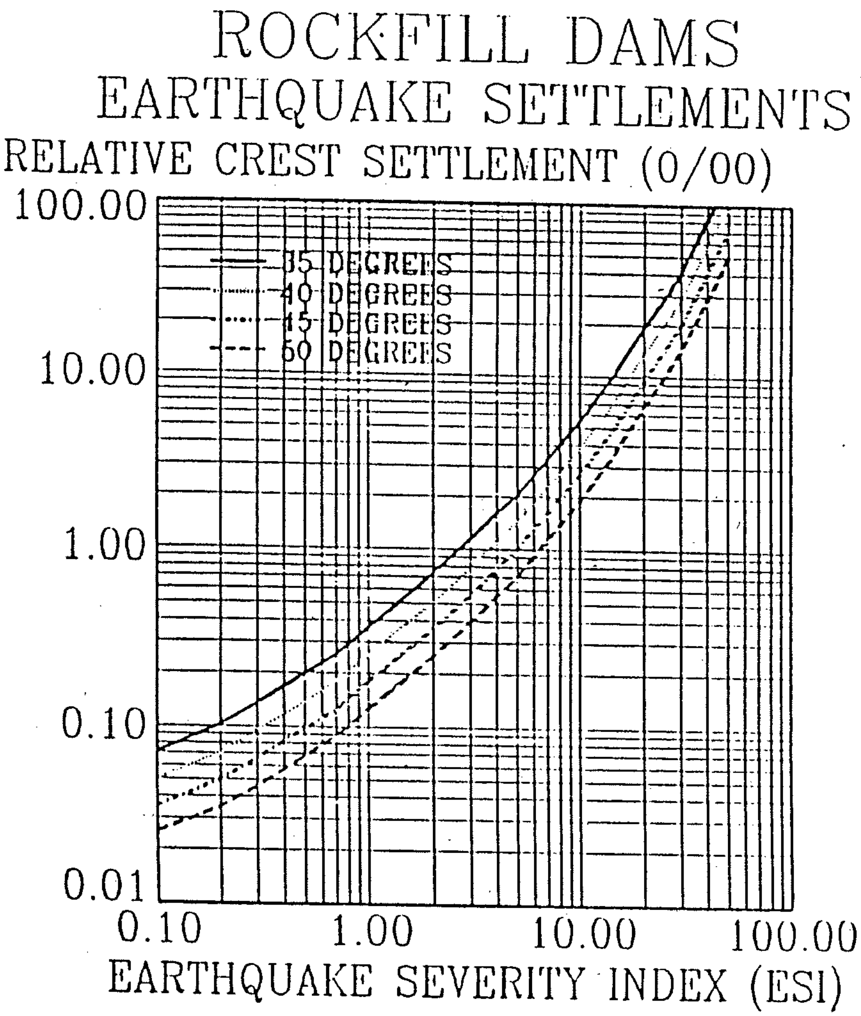

Fig. 5

Influence of Friction Angle on Settlements Computed for Rockfill Dams

Table 2

Relative settlement and ESI Data

Name of Dame	M	PGA	Vert Def. (cm)	ESI	Settlement ‰
Terror Lake	8.5	0.35	60 (e)	22.4	12
	6.5	0.50	30 (e)	4.0	4
Cogoti	7.9	0.19	40	7.5	4.71
Colbún	8.25	0.40	211 (e)	21.1	18.39
Pehuenche	8.25	0.33	279 (e)	17.4	31.35
Pueblo Viejo	8.25	0.65	445 (e)	34.3	33.46
Cirota	6.5	0.35	30 (e)	2.8	2.40
Miboro	7.0	0.20	3	3.1	0.23
Minase	7.5	0.08	6.1	2.2	0.91
	6.9	0.02	0.7	0.3	0,10
La Villita	5.9	0.09	2.5	1.57	0.42
	7.2	0.08			
	7.6	0.13	4.5	2.98	0.75
	7.3	0.13	14.4	2.20	2.40
	8.1	0.28	45.2	9.33	7.53
	7.5	0.04			
Infiernillo	5.9	0.08	3.5		0.41
	7.2	0.09	2.5	1.77	
	7.6	0.12	13.0	3.57	0.88
	8.1	0.14	11.0	6.53	0.74
	7.5	0.06			
Chicoasen	7.0	0.85	100 (e)	13.3	4.17
Fortuna	7.5	0.40	80 (e)	10.8	7.62
Oroville	5.7	0.10	0.9	0.2	0.04
Leroy Anderson	6.2	0.41	1.5	2.0	0.21

(e) = estimated
All others are actual measurements

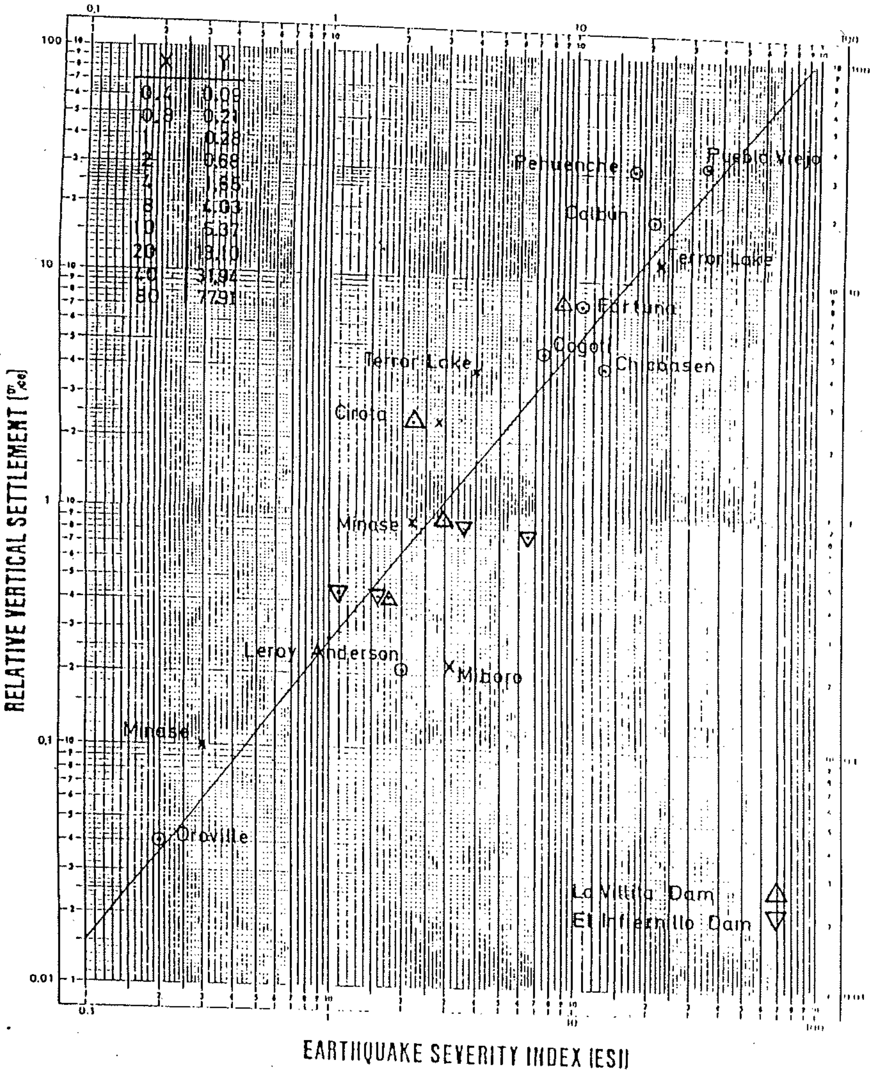

Fig. 6

Relationship between Crest Settlement and *ESI*

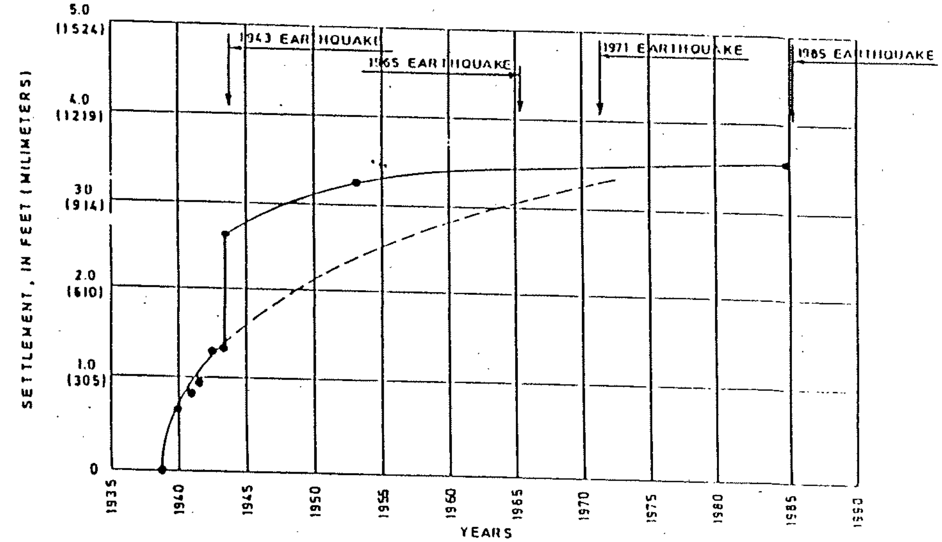

Fig. 7

Crest settlement curve

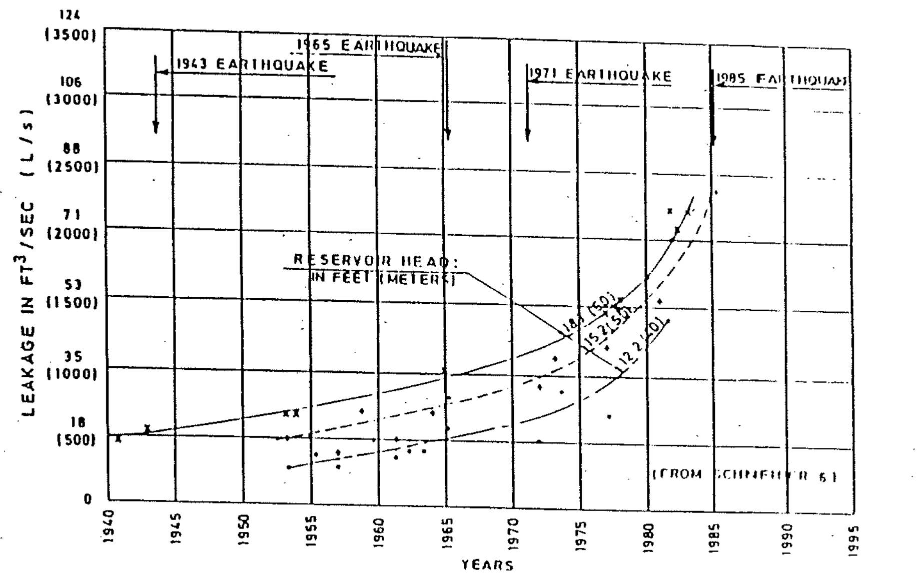

Fig. 8

Leakage at Cogoti Dam

for research and suggested introdu g the strength of the rockfill as a parameter as shown in Fig. 5.

Some extra data from chilean dams have been added to the correlation, the estimated settlements of Colbun and Pehuenche dams (central core gravel fill) as shown in Table 2 and Fig. 6. A power fitting curve has been obtained in the form :

$$Y = a X^b$$

in which :

$a = 0.28$
$b = 1.29$

with an r^2 value of 0.84.

Probably future research should be focussed to correlate Earthquake Severity Index and relative settlement as functions of yield accelerations. It is appropriate to mention that Cogoti being one of the few concrete face rockfill dams submitted to a strong earthquake, and settled 0.40 m is now leaking 2.5 m^3/s for high reservoir levels. This leakage increase has evolved smoothly as it can be appreciated in Fig. 8.

3 — W. PIRCHER *(Austria)*

SOME GENERAL REMARKS ON BITUMINOUS CONCRETE CORES

Dams featuring bituminous concrete cores are still not very common, although the technique appears to be well established by now (see ICOLD Bulletin 42 of 1982). The number of successful applications — and there is no exception to the negative — is increasing steadily, and so is the height and surface area of the core membranes. Several dams with cores about 100 m high are in operation with very satisfying results (e.g. leakage in the order of a few liters per second), more and even higher ones are under construction or being planned. A few general remarks might be useful as a background for the more specific contributions expected to this topic (Fig. 1).

The original methods of core placement based on manual work like the cyclopean mortar core are, if not disappearing at all, limited to small dams. The future is undoubtedly with mechanical placement by special core placing units as introduced in 1962 and carried out for many years exclusively by the German Contractor Strabag. Meanwhile, improved versions of the original procedure and equipment of a type which Strabag calls the « Third Generation » have become available with a number of specialized contractors. The management of Strabag may regret this, but it is also a compliment to the engineering quality of their pioneering work. Now for the further propagation and progress of machine-placed asphaltic

DAMS WITH BITUMINOUS CONCRETI

Dam	Country	Year of Completion	DAM Height [m]	DAM Crest Length [m]	Height [m]	T
TELMAMSKAYA	USSR	U.C.	140	1100	130	
HIGH ISLAND EAST	Hong Kong	1977	109	420	105	
FINSTERTAL	Austria	1980	150	652	96	
STORVATN	Norway	1987	90	1460	90	8
HIGH ISLAND WEST	Hong Kong	1977	101	720	90	
IRGANAISKAYA	USSR	U.C.	100		80	
BOGUCHANSKAYA	USSR	U.C.	82	1860	79	
KLEINE KINZIG	FR Germany	1983	65	330	65	
DHÜNN (Main Dam)	FR Germany	1981	62.5	390	58	
MEGGETT	United Kingdom	1982	56	550	50	

Fig. 1

concrete cores there can be nothing better than a numbe contractors — competent specialists, mind you, not just lo

Mix design has become rather uniform, owing to the r successful experience. With modern equipment and caref cessing, placement and compaction of bituminous concre assured regular quality of an industrial product — as requ relatively thin but vital element (Fig. 2).

All doubts voiced by Terzaghi 30 years ago in son provocative and stimulating questions have been clear meantime by numerous tests and the experience with ma sealing elements of dams in operation. Bitumen will not flo granular skeleton of the mix, not even under high hydrosta adhesion to the mineral grain will not be affected by water, core material nor its bitumen content will enter into the adja or filter zone provided a certain relation of the grain sizes

Ageing of bituminous concrete should not be a probl protected position of a core membrane, but we have of c proof yet for the span of many centuries which our large expected to last. At Finstertal dam, we therefore have plac strip of four layers at a suitable location on the reservoi