The drains are installed in non-erodible materials (rock, concrete); in the fill or foundation soils, they are replaced by filters or a filter is placed at the interface of the base material and the drain.

Compaction Requirements :

Previous requirements (Hydro-Quebec) to compact filters to 70-80 % relative density, seems to have favored the development of arching phenomenon, which is probably responsible for the occurrence of some horizontal cracking, and consequently of concentrated leaks, as experienced at Manicouagan 3 Main Dam. Considering that the relatively uniform sand (concrete sand), used as filter for glacial till protection, can be easily compacted, the compaction requirement for filters have been relaxed; compaction achieved only by the movement of transportation and spreading equipment seems to become acceptable.

Development of cracks and their danger were emphasized by Prof. A. Casagrande :

' Another mistake is to design the filter zones between a core and a downstream rockfill zone too thin. When tension cracks develop through the core they are liable to propagate through the filter layers and then the protection of the core is lost. '

In this context, Prof. A. Casagrande has advocated the use of an adequate upstream filter also. While observing that some of the crackings (fissures) can develop before the reservoir is filled, he made the following comments :

' If filling is carried out slowly, such cracks may heal themselves by swelling and/or infiltration of fines from the upstream filter or transition zones. When filling is done rapidly, such cracks may become wider due to the hydrostatic pressure in the crack; and then the tendency may develop for the crack to propagate through thin filter zones. This is particularly dangerous if the downstream shell consists of coarse rockfill. ' "

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Prof. de Mello emphasizes the need for chimney filter/drain systems within the embankment dam. Once this is accepted as a fundamental requirement, the next important consideration becomes compatibility of deformability between zones. Stress and strain redistribution, and hang-up of core on stiff vertical or nearly vertical granular filter/drain systems become important.

Prof. de Mello provided the following references :

de Mello, Victor F. B., 1975, excerpt from paper presented in the 6th Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Durban, South Africa, September, Vol. II, pp. 303-304. This excerpt provides a

simple test on the gradation curve to check unacceptable gap grading with respect to internal instability.

de Mello, Victor F. B., 1987, Section 44.4.4, Filter transition materials, Section 44.4.5, Well-graded materials of wide range of grain sizes. *Ground Engineer's Reference Book*, Butterworth's, London.

de Mello, Victor F. B., 1977, "The Rankine Lecture", *Geotechnique*, *27*(3), pp 279-355, September.

Silveira, A., 1965, "An Analysis of the Problem of Washing Through in Protective Filters", *Proceedings*, 6th International Conference on Soil Mechanics and Foundation Engineering, Vol. II, pp 551-555, Canada.

Varde, Oscar, 1989, excerpt from theme lecture "Embankment Dams", *Proceedings*, 12th International Conference on Soil Mechanics and Foundation Engineering, Rio de Janiero, August.

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The following response to the questionnaire was provided :

" Evolution of Filter Design and Construction – During the 1940's and 1950's, the use of granular filters in earthfill embankment dams was incorporated by zoned cross sections with chimney drains and drainage blankets. Corps of Engineers filter criteria were used for designing filter material gradation. During the 1960's, single layer filter material was used with broad gradation.

Design Requirements and Construction Practices. – The general design criteria for filters follow Corps of Engineers filter criteria for retention and permeability requirements. The maximum size of filter material is restricted to 75 mm, 40 to 55 percent passing the No. 4 sieve, and no more than 5 percent passing the No. 200 sieve. Construction control includes placement of filter materials in horizontal lifts and compaction by smooth-drum vibratory roller. Filter materials are compacted in layers of 9 inches to a density of at least 70 percent relative density.

Case Histories. – Iron Canyon Dam was designed by Pacific Gas and Electric in the early 1960's, located on Iron Canyon Creek, a tributary of Pit River. It is a homogeneous earthfill embankment with a vertical chimney filter and blanket drain. The chimney filter is 12 feet wide and designed to allow seepage flow without development of high pore pressure.

Controversial Issues. – Use of geotextiles as a substitute for granular filter should be considered in the following cases :

i) The geotextile filter could be included in the modified design (repair) of a dam to gain additional freeboard during flood loading.