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Permeability in Flysch - Distribution Decrease with Depth and Grout Curtains Under Dams

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Abstract: A considerable number of in situ permeability tests in flysch are processed to a depth of 120m with a good spatial distribution. The distribution of permeability values for the different litho-types of this formation, their comparison and their decrease with depth is discussed. The depth where a permeability of 3 to 5×10^{-7}m/sec can be retained (the limit of a reasonable grouting under a high dam) may be twofold if the geological history of the formation could not contain a compressional tectonic process. This depth may reach 100m in some cases. The differences in the mean values of permeability among the various litho-types are minor, while the presence of siltstones, always present although with varied participation, dramatically controls the global permeability.

Keywords: Permeability; Flysch; Dams; Grout curtain; Distribution with depth

Introduction

Low permeability formations may not be of interest in terms of water resources, but they may develop a permeable zone close to the surface where they exhibit a loose and open structure. The question then relates to the depth of this permeable zone and the mean value of the corresponding permeability. This is particularly important in the case of dam foundations and the design of the grout curtain beneath it. The answers on these questions depend on:

1. The nature of the rock, e.g. if it is strong with a brittle mechanical behaviour (e.g. crystalline rocks, sandstones), or to the contrary, soft and weak with a plastic behaviour (e.g. marls, siltstones, clay shales).
2. The geological history of the region and more particularly its tectonic evolution.
3. The paleogeographic development of the area and its morphology.

In this paper the flysch formation is discussed. Flysch, a typical impermeable formation, has the particularity of presenting alternations of strong brittle with weak plastic rocks. The latter strongly influence any tendency of development of permeability in the strong beds. Additionally, flysch suffers, by definition, from compression tectonics. In this paper the prevailing permeability values, their distribution and the trend of reduction with depth for the main litho-types of flysch are presented.

The data were collected in northern Greece from 213 packer tests from 108 boreholes during the site investigation for 8 tunnels in regions with extended development of flysch. The investigated depths reached 120m. The tests in the weathered mantle of the formation close to the surface were

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excluded from the analysis of the results. The length of each tested section was 5m (rarely 3m). The side distance of the boreholes from the valley slopes were much bigger than their depth. Thus no lateral loosening of the mass could influence the results.

1 Flysch and Its Litho-types

Flysch consists of varying alternations of clastic sediments that are associated with orogenesis. It closes the cycle of sedimentation of a basin before the “arrival” of the paroxysm folding process. The clastic material derives from erosion of the previously formed neighboring mountain ridge. Thus the formation suffered from this compression process and is disturbed with folds, inverse faults and sheared zones.

Flysch is characterized by rhythmic alternations of sandstone and fine grained (pelitic) layers.

The most common litho-types of flysch are (Marinos 2007):

1. Thick bedded sandstone with thin intercalations of siltstone (Type A). The percentage of sandstones varies from 70 to 90%. The thickness of the sandstone beds varies from some tens of dm to about 1m.
2. Bedded siltstone with some intercalations of thin sandstone (Type B). The siltstones persist with a participation of 70 to 90% and they retain in most cases their bedding in depth. The thickness of beds is of the cm or dm scale. The bedding may be imperceptive only if the flysch has not suffered much from the folding process. The few sandstone intercalations have a thickness of about 5 to 15cm. In cases of intense folding sheared zones are present with a chaotic structure and a transformation of the fine grained rocks into a clayey like mass.
3. Alternations of sandstones and siltstones in about equal participation (Type C). The alternating members have a thickness of the scale of dm or m. In the zones of tectonic disturbance the sandstone beds are heavily broken and the siltstone beds deformed and squeezed.

As mentioned, 213 tests were performed. From those 137 could be attributed to one of these particular litho-types: 40 for type A, 57 for type B and 40 for Type C.

2 Global Permeability - Decrease with Depth and Grout Curtains Under Dams

From the 213 tests, where all the litho-types are included, the mean value down to a depth of 120m was found as 4.6×10^{-7}m/sec. The distribution is shown in Figure 1. There is a tendency for an exponential distribution and the standard deviation is quite high, 6.8×10^{-7}m/sec. If the tests from great depths are removed, together with those close to the surface, the mean permeability value for a zone from a depth of 10m to 70m becomes 5.3×10^{-7}m /sec, slightly increased by 10%.

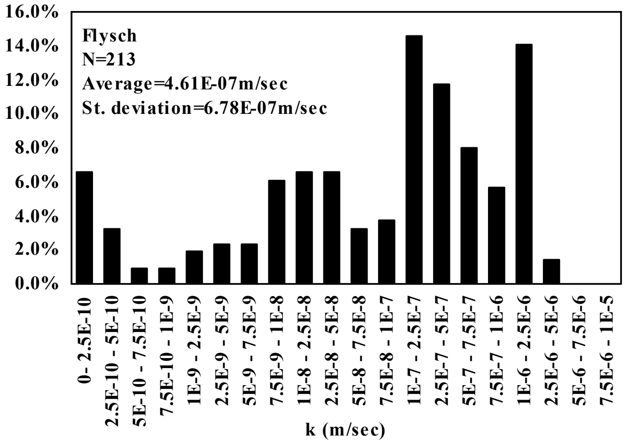

Figure 1 Distribution of permeability for flysch up to depth of 120m – all litho-types

These values correspond obviously to a low permeability rock mass when this mass is considered globally. However, for high dam construction it is necessary to consider the distribution and decrease with depth. This distribution is shown in Figure 2.

From this figure it is clear that there is a high scatter of the distribution of permeability values in relation with depth, practically in all depths, although there is clear progressive decrease to lower values. The dispersed character of values can be explained by the tectonic history of flysch which provoked a disturbance to the formation, allowing fractures to be present and retained open at depth.

In the case of high dams, if we consider a permeability value of 3 to 5×10^{-7}m/sec (approx 3-5

Lugeon units) as a guidance limit for a grout curtain (Houlsby 1985), a depth of down to 100m might be considered. Although this conclusion is general, as it embraces all litho-types, it is of value as in a dam site the various litho-types may alternate. Finally there is very little difference among the permeability of these litho-types as it is discussed in the following paragraph. It should also be clear that the design of a curtain is a site specific issue and depends on site characteristics. These characteristics include an increased presence of clay shales in the siltstone litho-type which can reduce the needs for grouting dramatically, or the presence of fractured zones in the sandstone sequence which may impose a prolongation of the curtain.

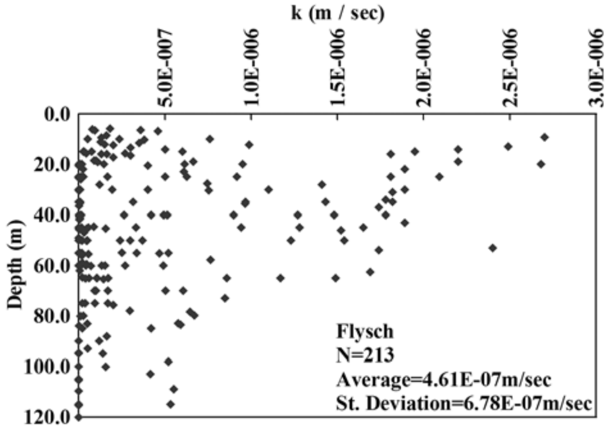

Figure 2 Decrease of the permeability with depth in flysch – all litho-types

Here after is the practice applied in a number of dams in Greece:

1. Evinos 124 high earthfill dam, on litho-types A and C, tectonically disturbed: The curtain reached a depth of 70m from the foundation level, which however was at -50m from the initial ground surface. This ground removal was imposed by the poor strength of the flysch, unable to offer an acceptable foundation at an elevation close to the surface. The grout used had a composition which was at the beginning of the injection 2/1, ending to 1/1 water/cement. Bentonite was added at 2-3% by weight of cement. (Marinos et al. 1995, Dounias et al. 1997, figure 3).
2. Mornos 126 high earthfill dam, on litho-type C. The curtain ended beyond the depth of 100m in the disturbed right abutment (Marinos 1982).
3. Politses 40m high earthfill dam. It was necessary to grout to a depth of 40m (Liakouris 1995).
4. Kastraki 97m high earthfill dam, on litho-type A and C, with no significant tectonic disturbance. The curtain reached a depth of 50m. (Liakouris 1995, figure 4).

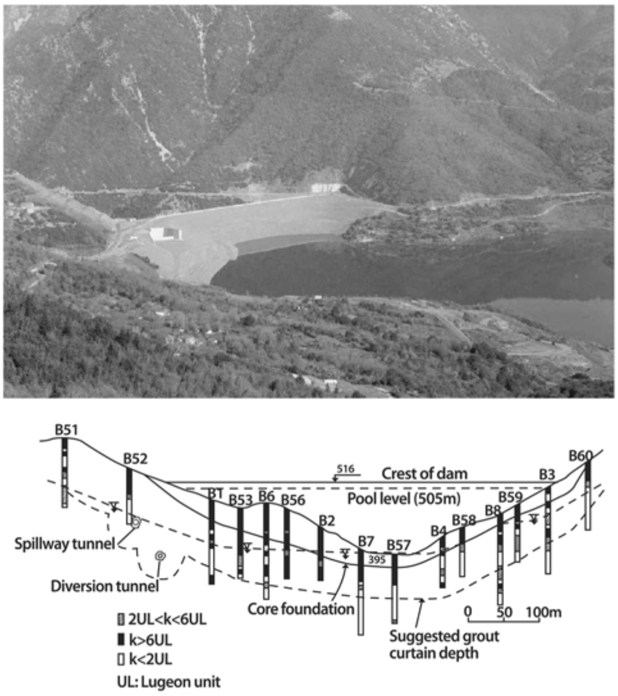

Figure 3 Evinos Dam and longitudinal section with permeability data (Marinos et al. 1995)

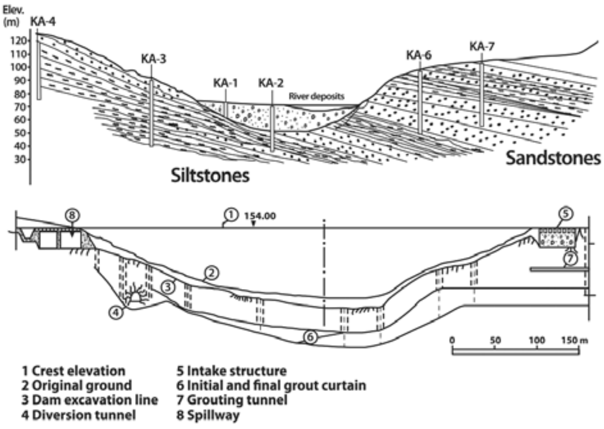

Figure 4 Kastraki Dam and grout curtain (from Liakouris 1995)

5. Pournari 107 earthfill dam, on all litho-types with no significant tectonic disturbance: The grout curtain reached 60m (Liakouris 1995).
6. Rhodes, Gadouras 67m earthfill dam on litho-type B with high presence of clay shales. Only carpet grouting of a depth of 10m was constructed to prevent erosion. (Marinos et al. 2008).

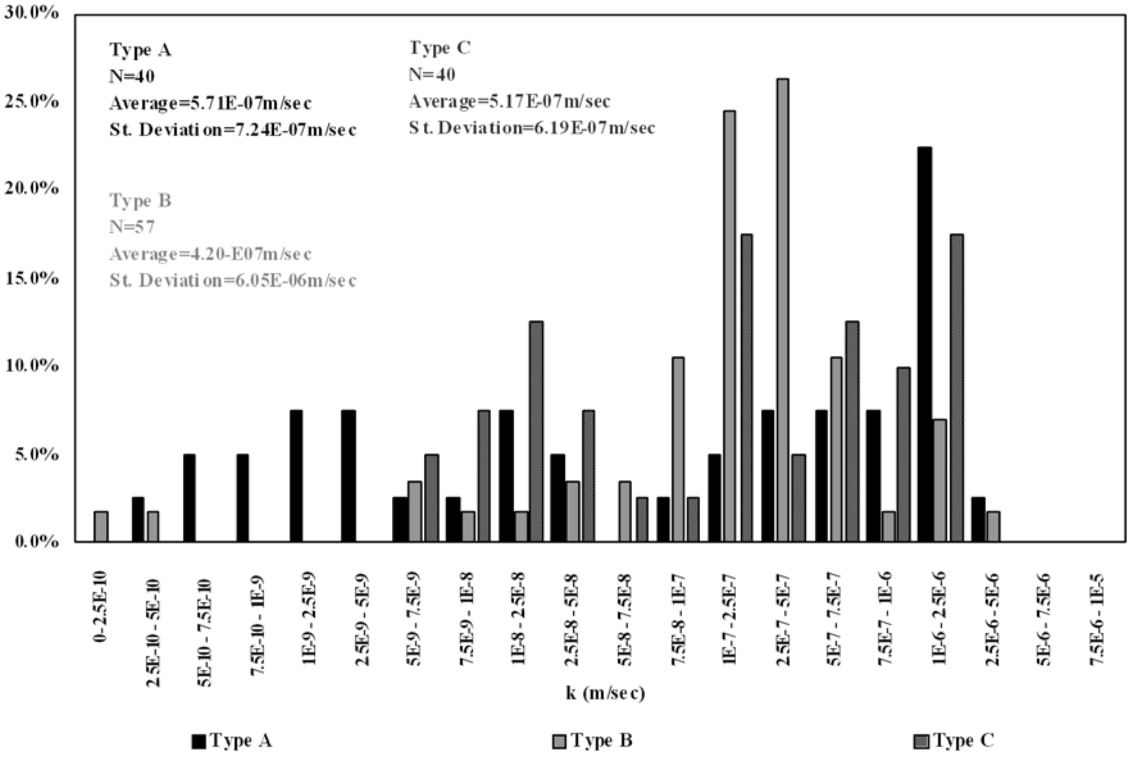

Figure 5 Distribution of permeability for the three main litho-types of flysch

3 Comparison of Litho-types

The distribution of the permeabilities of the 3 main litho-types is shown in Figure 5. The mean values are:

Type A (persistence of sandstones): 5.7×10^{-7}m/sec (40 tests)

Type B (persistence of siltstones): 4.2×10^{-7}m/sec (57 tests)

Type C (alternations): 5.2×10^{-7}m/sec (40 tests)

All types: 4.6×10^{-7}m/sec (137 plus 76 undifferentiated, 213 in total)

The differences are very low, with the type A to be as expected, more permeable. The small difference can be explained from the tectonic history of the flysch formation where a “homogenization” is achieved from the compression and folding process. The low values in the sandstone type are imposed by the barriers of the thin interlayers of siltstones which may also intrude in major fractures of the sandstone beds.

4 Conclusions

The analysis of a good number of in situ permeability tests in the various litho-types of flysch reveal the low permeability of its rock mass with very small differences among the types. The role of the presence of siltstone interlayers is predominant in all types, even in those types where their participation is very low. Additionally, the history of compression tectonics, from which the formation suffered, led to a homogenization of all types in terms of mean permeability values. This value is of about 5×10^{-7}m/sec for the first tens of meters below surface. The decrease in relation to depth is progressive but with significant scatter. Taking into account a limit of 3 to 5 Lugeon, the depth of the grout curtain necessary for high dams may be of some tens of meters in the case where the flysch is not particularly tectonized and can reach 100 or even more meters when it is heavily disturbed.

Acknowledgments

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