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Dimensioning the Filtration Properties of Geotextiles Considering Long-Term Conditions

Evaluation des propriétés filtrantes des géotextiles en tenant compte des conditions à long terme

For dimensioning the mechanical and filtration properties of geotextiles there have till now been no sufficient proposals which take into consideration the interaction of geotextile and soil. Within the scope of a special research program, several geotextiles (woven and non-woven) were dug out of existing revetments on seadikes and inland waterways to test their mechanical and filtration properties. This paper gives the results of testing the filtration properties and describes a method for dimensioning the filtration properties of geotextiles. Developed filtration rules and diagrams to estimate the reduction of permeability to water in virgin fabrics provide a complete formula for solutions which takes into consideration the interaction of geotextile and soil (blocking and clogging). There is also a description of the test procedures for checking the opening size and permeability to water of geotextiles as basic data for dimensioning filtration properties.

Jusqu'ici il n'existait encore aucune proposition ni pour la mesure mecanique ni pour la mesure des propriêtés filtrantes, qui tienne suffisamment compte de la correlation entre géotextile et sol. Dans le cadre d'un programme d'études spécial une série de géotextiles (tissés et non-tissés) ont été déterrée de déjà existants revêtements de digues de mer et de voies navigables, pour contrôler la solidité et les propriétés filtrantes. Ce contribution décrit les résultats de l'étude des propriétés filtrantes et présente une méthode pour la mésure des propriétés filtrantes de géotextiles. Avec les règles de filtrage et les diagrammes permettant de déterminer la diminution de perméabilité de géotextiles neufs sortant d'usine, il donne une esquisse complete de solution, qui tienne compte de l'influence réciproque de géotextile et sol (blocking/clogging). Les méthodes de contrôle des valeurs base du géotextile (largeur d'ouverture et perméabilité) y sont également décrites.

INTRODUCTION

In a given application, a geotextile can perform several different functions. But in many cases one of the functions is to act as a filter to prevent the wash-out or passing of fine soil particles in connexion with a sufficient permeability to water.

For describing the mechanical and filtration properties of geotextiles there exist a lot of laboratory tests but most of them only allow to compare the properties of different geotextiles and are not useful for dimensioning a geotextile at a given application. Not enough valid informations on fabric properties are gathered in order to predict accurately the behaviour of such materials in field conditions. This underlines the necessity of field investigations or large scale modelling to collect data and informations on the interaction of geotextile and soil.

In 1979 and 1980 the Franzius-Institut for Hydraulic Research and Coastal Engineering of the University of Hannover, W.-Germany, has carried out extensive field investigations on long-term behaviour of geotextiles in coastal structures. This investigations were completed by field studies of the Federal Institute of Waterways Engineering (BAW) at river and canal revetments.

This paper will only deal with the results of filtration properties of geotextiles, other properties such as mechanical and chemical will thus be discarded. Results on the long-term resistance of geotextiles in coastal structures based on the mentioned investigations are given in separate puplications in 1980 by Georg Heerten (2).

1. FIELD STUDIES ON GEOTEXTILES

1.1 Research Program

The research program carried out at the Franzius-Institut for Hydraulic Research and Coastal Engineering of the University of Hannover was devided in five parts:

a) Evaluating the experiences in the use of geotextiles in coastal and hydraulic engineering sending extensive questionnaires to the engineering authorities

b) Developing test methods to estimate the filtration properties of virgin fabrics of dug out geotextiles as well

c) Digging out geotextiles of coastal structures being in function for many years

d) Investigating the mechanical and filtration properties of the dug out geotextiles and of the virgin fabrics

e) Developing a dimensioning method to fulfil and calculate the retention of solid particles and the permeability to water considering the interaction of geotextile and soil

The most important part of the research program was the investigation of the properties of the fabrics dug out. For samples dug out of revetments the following individual investigations were carried out:

a) Condition of the revetment (profile changing)

b) Condition of the geotextile

c) Testing the tensile strength and elongation

d) Testing the filtration properties

e) Testing the fabric weight and soil content

f) Grain-size analysis and permeability test of the subsoil

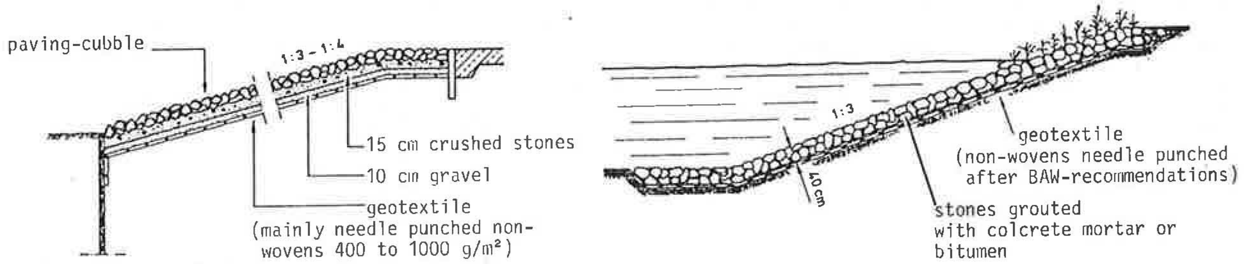
For fabric samples of other coastal structures (sand bags, sand filled tubes) the research program was reduced to the individual investigations of fabric condition, tensile strength, opening size of the fabric and grain-size analysis of packed soil. In relation to the long-term filtration properties in this paper only the results of testing d) to f) are discussed and presented.

In the meantime it is possible to consider also the first results of the investigation program of the Federal Institute of Waterways Engineering (BAW) digging out some non-woven geotextiles at revetments of canals and rivers. By order of the Federal Institute of Waterways Engineering the Franzius-Institut has investigated the filtration properties of these fabrics too.

1.2 Investigated Geotextiles and Structures

At different locations at the German Northsea coast and at canals and rivers in the northern part of Germany the geotextile samples were taken. 16 samples (12 non-woven, 4 woven fabrics) were dug out of revetments of seadikes, 6 samples of non-woven fabrics are originated from inland waterways. The general layout of the revetment structures is shown in Fig. 1.

At the seadike revetment the subsoil is covered by the geotextile and the geotextile itself is covered by a 10 cm gravel layer, 15 cm crushed stone layer and a heavy paving-cobble. In contrast to this the revetments of the inland waterways are composed of the geotextile and a heavy rip-rap layer grouted with concrete mortar or bitumen. Fig. 2 gives an impression of the sampling operation and in Fig. 3 a non-woven geotextile is shown after removing the cover layers of the revetment.



Seadike Revetment

Inland Waterway Revetment

Fig. 1 Layout of the seadike revetments and revetments of inland waterways

Fig. 2 Digging out a fabric at a seadike revetment at the Northfrisian coast

Fig. 3 Non-woven needle punched fabric after removing the cover layers

1.3 Some Special Results

The first important result which could be noticed already at the site was the extensive incorporation of soil in the non-woven fabrics. Caused by the soil incorporation the mass of the samples came up to 10 kg/m². In table 1 the characterizing data of the non-woven samples and the estimated soil content are given. This high clogging rates illustrated in Fig. 4 should be used as a scale for laboratory test, testing non-woven fabrics with soil.

Fig. 4 Non-woven needle punched fabric filled up with soil particles

In most cases the incorporation of soil particles in comparatively short laboratory test will be only a small fraction of the observed amount of the field studies. Based on the actual knowledge and experience of the author there exist only one test method giving results similar to natural clogging conditions: the turbulence test of the Federal Institut of Waterways Engineering (BAW). The BAW-turbulence test is a special developed test for investigating the filtration properties of thick multilayer needle punched non-woven fabrics being used in revetments of waterways on fine soils in Germany, H.J. List (4).

The second important result is the observed difference between the thickness of the dug out non-woven fabrics and the thickness of the fabrics under given revetment load conditions (10 kPa) after washing out most of the incorporated soil (in average 90% of the incorporated soil could be removed). Table 2 gives for example the thickness of some dug out samples at a measuring load of 2 kPa and the thickness after removing the soil and bringing up the revetment load of 10 kPa.

Table 2 Difference in thickness of dug out fabrics and fabrics after washing

Sample No.	Thickness at 2 kPa containing soil mm	Thickness at 10 kPa after washing mm
13	7,1	5,7
14	7,9	6,4
15	4,2	2,9
16	5,8	3,6

Table 1 Description and technical data of investigated non-woven geotextiles and estimated fabric soil content

No	description in brief	year of installation	fabric mass g/m²	thickness at 2 k Pa mm	soil content g/m²
1 2 3	combination of non-woven fibre fabric and woven-scrim; coarse PA 6 fibres 350 dtex; needle punched and chemical bonded	1970 1970 1970	827 1492 1162	7,5 8,0 8,0	8898 8361 9280
4	non-woven fibre fabric needle punched and chemical bonded; PES fibres ~3-6 dtex	1971	487	2,7	1187
5 6	combination of a fine (~6 dtex PES) and coarse (~350 dtex PA) non-woven layer and a woven scrim; needle punched	1974 1974	847 903	6,1 6,6	3149 4123
7 8	combination of non-woven fibre fabric (PES ~5 dtex) and woven scrim; needle punched and chemical bonded	1974 1974	354 404	2,2 2,2	956 679
9	non-woven spun fabric; ~6 dtex PES; needle punched	1974	351	2,7	1348
10	combination of non-woven fibre fabric (PA 6 6-17 dtex) and woven scrim; needle punched and chemical bonded	1974	422	3,3	1358
11	non-woven fibre fabric; 3-6 dtex PES; needle punched	1974	413	3,4	1283
12	non-woven fibre fabric; 3-6 dtex PES; needle punched; combined with a scrim	1974	406	2,9	2106
13 14 15	combination of non-woven fibre fabric and woven scrim; coarse PA 6 fibres 350 dtex; needle punched and chemical bonded	1971 1970 1972	1071 1327 872	7,1 7,9 4,2	3686 4867 2059
16	non-woven fibre fabric 3-6 dtex PES, needle punched	1977	856	5,8	2627

The observed variation of the thickness lead to the assumption that the thickness of needle punched non-woven fabrics didn't decrease during installation as given by laboratory test for testing the compressibility or the permeability under compression. In these tests the geotextile is symmetrically compressed by e.g. horizontal plates without contact to soil particles. Under field conditions and during installation the decrease of the thickness of non-woven needle punched fabrics evidently is influenced by the given interaction of geotextile and soil and the construction work itself. This observed behaviour of needle punched non-woven geotextiles may improve the conditions of permeability and friction.

In Fig. 5 some data of the virgin non-woven fabrics (porosity n, permeability k_n) and of the dug out fabrics (pore space clogged by soil, remaining porosity n', remaining permeability k_n') are given.

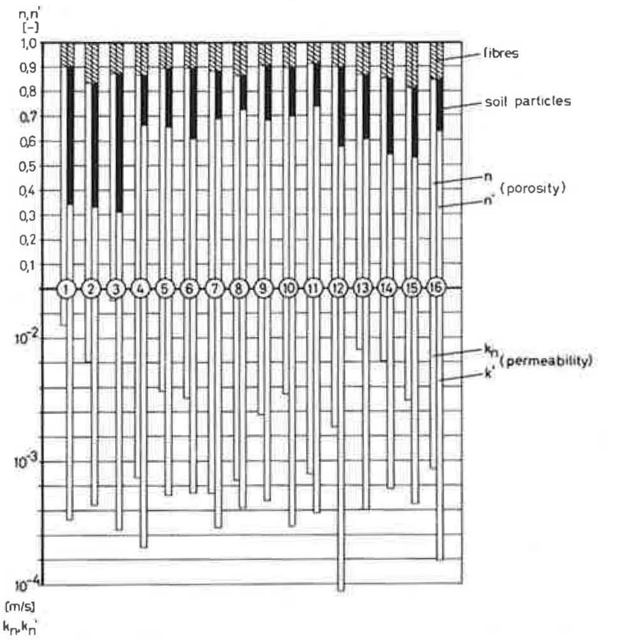


Fig. 5 Clogging of voids volume and decrease of permeability of non-woven needle punched fabrics

A significant decrease of permeability of the needle punched non-woven fabrics can be seen, but compared with the estimated permeability of the soil (permeability coefficient for location 1 to 12 $k \sim 1{,}0$ to $5{,}0 \cdot 10^{-5}$ m/s) the permeability of the clogged fabrics is 5 to 12 times higher as the soil permeability (1). The remaining porosity of n' = 0,32 to 0,74 guarantees a sufficient long-term permeability.

In contrast to these results for most of the woven fabrics investigated in this program a lower permeability coefficient as given by the soil was estimated. The relation of the permeability of the woven geotextiles and the permeability of the soils was in the range of 0,16 to 1,8.

These results underline the advantageous filtration properties of non-woven needle punched geotextiles.

2. FILTRATION PROPERTIES OF GEOTEXTILES

2.1 Dimensioning

A new dimensioning method to select a fabric allows to fulfil and calculate the requirements of sand tightness as well as the requirements of the hydraulic permeability of geotextiles. Fig. 6 shows a flow diagram explaining the procedure to select a fabric according to the characteristics of the subsoil and the construction. in the first step we have to estimate the effective opening size O_{90}. O_{90} required is given by filtration rules as a function of the particle distribution curve of the soil and the load conditions.

In the second step the hydraulic conditions have to be controlled. To prevent over-pressures in a revetment-construction the permeability of the filter fabric has to be higher than the permeability of the subsoil. Special investigations were carried out to consider the decrease of the permeability of woven fabrics by blocking and non-woven fabrics by clogging. Now, as a result of the investigations, it is possible to estimate a permeability-reduction factor as a function of fabric data and soil characteristics. Only für non-woven fabrics, when the effective opening size is small in relation to the diameter of soil particles, an additional restriction is given by $O_{90} < 0.5 \cdot d_{10}$ leading to a η_v value $\eta_v = 1.0$. The permeability of the fabric is sufficient when

$$\eta_{V/G} \cdot k_n \geq k$$

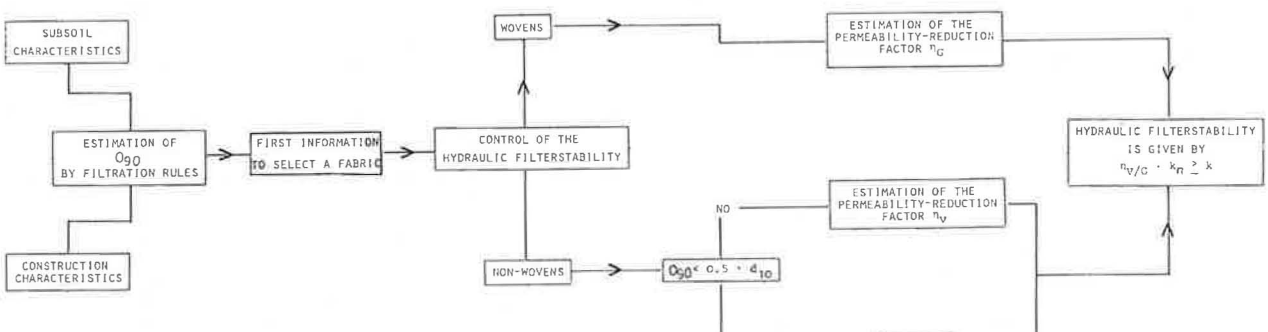


Fig. 6 Flow diagram to check the filtration properties of geotextiles

The filtration rules to fulfil the sand-tightness are determined as follows:

a) non cohesive soils

static load conditions: $C_u \geq 5$ $O_{90} < 10 \cdot d_{50}$ and $O_{90} \leq d_{90}$

static load conditions: $C_u < 5$ $O_{90} < 2.5 \cdot d_{50}$ and $O_{90} \leq d_{90}$

dynamic load conditions: $O_{90} < d_{50}$

b) cohesive soils and all load conditions:

$O_{90} < 10 \cdot d_{50}$ and

$O_{90} \leq d_{90}$ and $O_{90} \leq 0{,}1$ mm

Static load conditions are given by laminar flow including the change of flow direction. Dynamic load conditions are given by high turbulent flow, wave attack or pumping phenomenon.

Fig. 7 is showing the diagram to estimate η_G. η_G is given as a function of the permeability of the fabric k_n and the soil parameter d_{10}. This diagram considers the knowledge that the permeability of woven fabrics in interaction with the soil is influenced by "blocking". The soil particles are blocking the fabric openings. Blocking occurs immediately after installation with only small temporary variations.

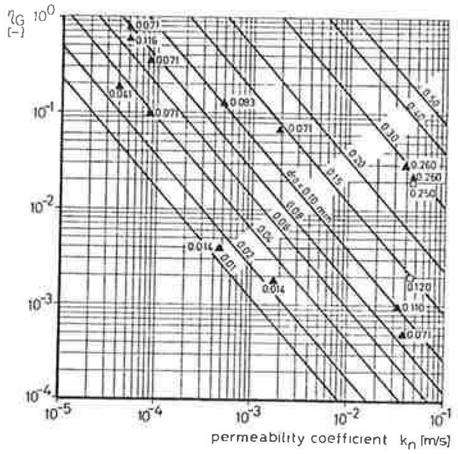


Fig. 7 Diagram to estimate the permeability reduction factor η_G for woven fabrics

In contrast to woven fabrics the permeability of non-woven fabrics is influenced by several parameters describing the "clogging"-behaviour:

- the porosity n given as the ratio between volume of voids and volume of solid elements of a geotextile (needle punched fabrics n = 0,8 to 0,9; $n = 1 - \frac{\mu}{\rho_f \cdot T_g}$)
- the thickness T_g of a non-woven geotextile. $n \cdot T_g$ is giving the total volume which could be filled up by soil particles by clogging.
- the opening size O_{90} of the fabric. O_{90} is including informations an fibre finess and the fabric structure
- the soil parameters particle size d_n and uniformity coefficient C_u and the load conditions

The results of the investigations on needle punched non-wovens showed that it is impossible to fill up the total voids volume by clogging (Fig.5). It can be seen that the interaction of fibres and soil is forming a stable filtration layer with a higher permeability as the soil permeability itself. Based on the collected datas in Fig. 8 a diagram is given to determine the permeability reduction factor η_V for non-woven fabrics as a function of the fabric parameters k_n, n, T_g and O_{90}. If the thickness T_g at 2 kPa and the permeability k_n at the given structure load conditions are considered, for practical use a sufficient safety is given.

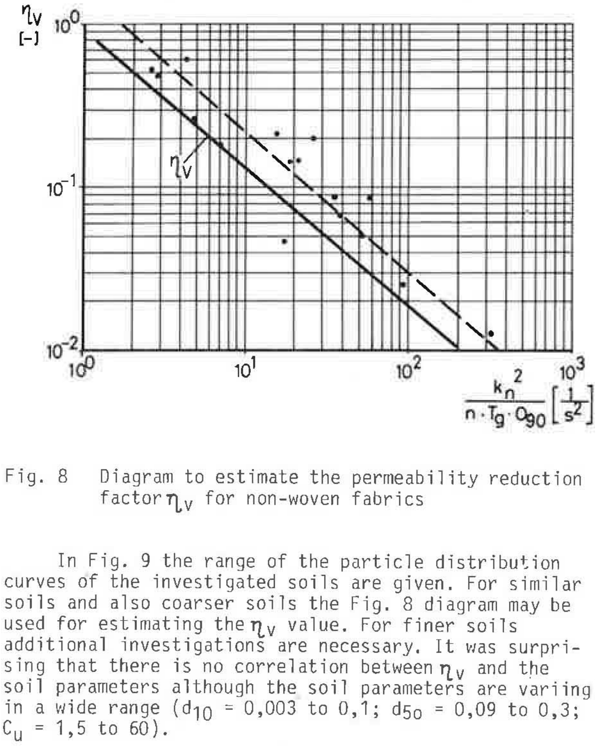


Fig. 8 Diagram to estimate the permeability reduction factor η_V for non-woven fabrics

In Fig. 9 the range of the particle distribution curves of the investigated soils are given. For similar soils and also coarser soils the Fig. 8 diagram may be used for estimating the η_V value. For finer soils additional investigations are necessary. It was surprising that there is no correlation between η_V and the soil parameters although the soil parameters are variing in a wide range (d_{10} = 0,003 to 0,1; d_{50} = 0,09 to 0,3; C_u = 1,5 to 60).

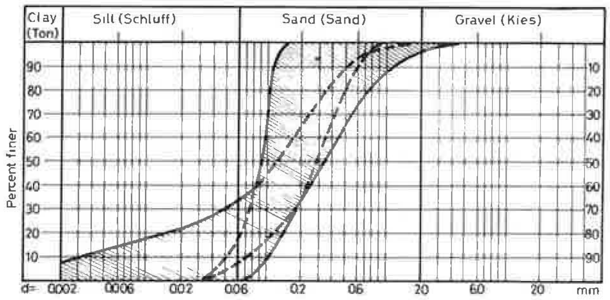


Fig. 9 Range of particle distribution curves at the sampling locations

2.2 Basic Test Methods

The investigation program also was including the development of test methods for testing the filtration properties of aged and virgin fabrics. For dimensioning the filtration properties of geotextiles only two tests have to be carried out giving the basic datas:

a) Testing the effective opening size

b) Testing the permeability as a function of superimposed load

The effective opening size of the geotextile is determined by wet sieving with a defind testing sand, composed of quartz particles. The grain-size distribution of the retained material and of the material passing will be determined leading to the effective opening size by a fixed evaluation method. Fig. 10 is showing the testing apparatus for the wet sieving operation. More details are given by Georg Heerten (1, 2).

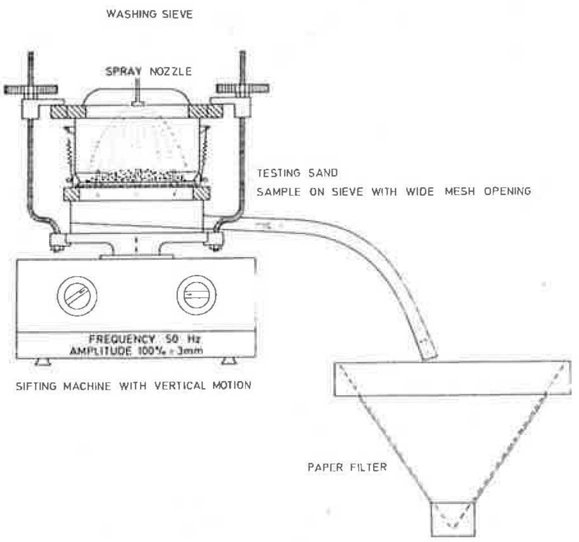


Fig. 10 Testing equipment for the estimation of the opening size of geotextiles

The permeability vertical to the plane k_n of a geotextile is determined in a permeability test with constant hydrostatic head generated by two overflow reservoirs.

Fig. 11 shows the test lay out. In the permeability cell a sample of several layers of the fabric is placed and after measuring the flow, the difference in piezometric level, the water temperature and the settlement of the sample a DARCY-coefficient can be determined. Repeating this procedure for various superimposed loads the permeability can be given as a function of load conditions.

Since 1978 these test methods are in a successful use at the Franzius-Institut for Hydraulic Research and Coastal Engineering of the University of Hannover, W.-Germany. In contrast to other known methods for determining the opening size the Franzius-Institut method is giving reproducable and trustworthy results.

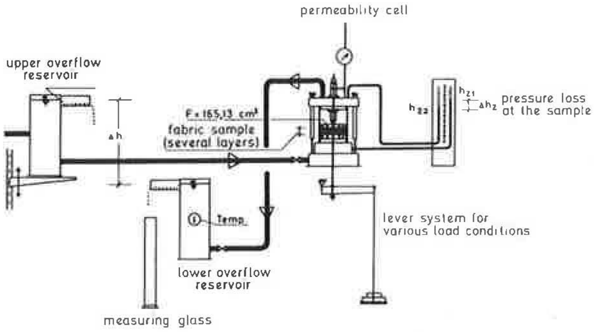


Fig. 11 Testing equipment for permeability test of geotextiles (normal to the plane)

CONCLUSION

Based on the research program (questionnaires and field investigations) especially for the application of fabrics in seadike revetments relating to the layout given in Fig. 1 some references to the mechanical properties of fabrics have been given (1, 3), requireing a minimum mass of non-woven of 400 g/m² and wovens of 225 g/m². In the meantime within a few days two severe storm floods attacked the Northfrisian coast in november 1981. These stormfloods clearly showed the safety and advantage of using heavy (~ 1000 g/m²) non-woven needle punched fabrics built up with fine and coarse fibres in seadike revetments.

These experience also underline the necessity of collecting field data for geotextile application and the author wants to request the engineers and scientists being involved on geotextile investigation to dig out fabrics, to control their conditions and to take these results as a guidepost for laboratory tests and recommendations for the application of geotextiles.

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