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Hydraulic Function and Performance of Various Geotextiles in Drainage and Related Applications

Performance et rôle hydraulique des géotextiles dans le drainage et les applications similaires

Many types of damage are caused when soil particles are moved by water, e.g., drainage systems without proper protection against piping of the soil become silted, clogged, and ineffective; river banks, lake and coastal shores are eroded; structures are undermined and become unstable, etc. The importance of protecting soil from piping or scouring by water is well recognized, and well-graded aggregate filters have conventionally been used. Geotextiles have demonstrated they can replace well-graded aggregate filters in many applications.

The function of geotextiles in drains and related applications is to permit water to pass through without reducing its rate of flow, while preventing the soil from being moved by water. As the geotextile performs in a geotextile - soil-water system, drain design criteria and the functional requirements of geotextiles should be based upon conditions of realistic soil-water-fabric interaction.

Les déplacements des particules de sol causés par l'eau sont à l'origine de nombreuses catégories de dégâts. Par exemple, les systèmes d'écoulement, sans une protection régulière contre l'hydrauliquement du sol, s'envasent, se bouchent et fonctionnent inefficacement; les rives fluviales, lacustres et marines s'érodent; les fondations, dégravoyées par l'eau, deviennent instables, etc. L'importance de la protection du sol contre l'hydrauliquement est bien reconnue, et cette protection est normalement obtenue au moyen de filtres d'agrégat convenablement classés. On a trouvé que les géotextiles peuvent, dans nombreuses situations, remplacer tels filtres d'agrégat. La fonction des géotextiles dans les systèmes d'écoulement s'agit de laisser passer l'eau sans affaiblir sa vitesse d'écoulement, tout en empêchant le déplacement du sol. Le géotextile fonctionne dans un système géotextile - sol - eau; par conséquent, les critères du projet et les fonctions exigées des géotextiles doivent être fondées sur les conditions véritables de l'action réciproque du système tissu - sol-eau.

INTRODUCTION

Engineering fabrics or geotextiles were at first slowly accepted as their uses represented a rather new concept lacking documented long term field experience. Uses of geotextiles in construction projects were at first considered novelties limited to "non-critical" applications.

Specifications are sometimes developed from limited experience and less fundamental data; but as performance mechanisms and requirements for long-lasting, non-clogging drain systems, protected by geotextiles, are better understood, specifications for geotextiles can be set for ensuring their desired performance. The keys to proper functioning of various systems are their design and construction. Some new design criteria are suggested.

In drainage and related applications the importance of protecting soil from being moved by water has long been recognized. Conventionally, well-graded aggregate filter systems have been used to keep the soil from piping or being scoured. Well-graded aggregate filters are designed to be able to hold the soil in place, but they must permit the water to flow at an unreduced rate, thereby avoiding a buildup of excessive hydrostatic pressure. The design and construction of well-graded aggregate filters depend upon the quality of the soil they must protect and the degree of water action. Proper design criteria and construction will influence the performance of aggregate filters.

WELL-GRADED AGGREGATE FILTERS

The pore openings between the aggregate filter particles should be small enough to prevent passage of most of the particles of the protected soil. But the filter layer should be permeable enough to permit unreduced flow of water from the protected soil to the drain without becoming clogged. A well-graded aggregate filter may be visualized as an obstable course through which piping soil particles must pass before they can be carried by water into the drain. Since an aggregate filter is made of loose particles, it must sometimes be built in multiple stages to be resistant against disintegration by water action, such as with soil erosion protection of stream banks, or of lake and coastal shores subjected to heavy waves.

Taylor (1) showed that a small sphere would move through the opening enclosed by three perfect equal size spheres if the diameter of the larger spheres is greater than six and one half times that of the small sphere (Figure 1A).

In a more unstable configuration of four equal size perfect spheres enclosing the opening, a small sphere would move through the opening if the diameter of the larger spheres is greater than two and one third times that of the small sphere (Figure 1B). An average opening size of the two configurations would be between 4-5.

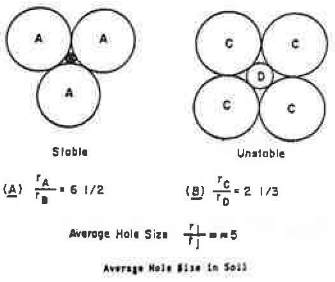


Figure 1

Bertram (2) established the filter design criteria:

$$\frac{D_{15} \text{ (of filter material)}}{D_{85} \text{ (of protected soil)}} < 8 \text{ to } 12$$

for protection against piping, and

$$\frac{D_{15} \text{ (of filter material)}}{D_{15} \text{ (of protected soil}} > 4 \text{ to } 5$$

for sufficient permeability to prevent buildup of hydrostatic pressures.

The U.S. Army Corps of Engineers (3), being more conservative, requires the following specifications be satisfied for protecting all soils, except for medium to highly plastic clays without sand or silt particles:

$$\frac{D_{15} \text{ (15\% size of filter material)}}{D_{85} \text{ (85\% size of protected soil)}} \leqslant 5$$

for protecting against piping, and

$$\frac{D_{50} \text{ (50\% size of filter material)}}{D_{50} \text{ (50\% size of protected soil)}} \leqslant 25$$

to ensure parallel grain-size curves of filters and protected layers. Multiple-stage filters are needed for medium to highly plastic clays.

Well-graded aggregate filters must often be hauled over long distances, and their quality, unless carefully monitored, might not be reliable. Their placement requires care because carelessly constructed filter systems could fail to function properly.

GEOTEXTILES

Geotextiles used for drainage and related applications should have functional criteria similar to those of well-graded aggregate filters. Fabrics should permit unreduced flow of water from the soil and simultaneously keep soil particles from piping or being scoured by water.

Often called filter fabrics, geotextiles for drainage and related uses actually do not perform as a true filter fabric. They function for an indefinitely long time without becoming blinded or clogged. True filters have limited functional lives as they eventually become blinded or clogged by continually accumulated particles. Geotextiles function properly by restraining the soil and keeping it from being moved by water. Actually, the soil body being restrained by the fabric holds soil particles in place.

Acceptance of geotextiles for civil engineering projects was at first slow as their use represented a relatively new concept. Hence, a few persons tried them only in "non-critical" applications. Over the years geotextiles have proven their good performance and as their uses grew rapidly, many suppliers entered the market with a variety of geotextiles having various fabric properties. In order to properly select a geotextile for a project, the fabric should satisfy the system's functional requirements with its structural and physical properties. A good understanding of the relationship between the relevant properties of geotextiles and their performance helps design engineers properly select and specify geotextiles for their projects. Key properties of geotextiles that are relevant and could influence their performance and functioning are:

- Structural features
- Ability to allow water movement without contributing to buildup of hydrostatic pressure, combined with ability to prevent soil movement by water.
- Adequate strength for withstanding normal, proper construction methods and for functioning through the service lives of projects.
- Dimensional stability and resistance to attack by microorganisms and chemicals to which the geotextiles are continuously exposed in the projects.

In a properly functioning drain constructed with a geotextile, water flowing from the soil into the drain can initially suspend and remove very fine surface soil particles through the fabric. This removal is not detrimental to the performance of the system. Suitable geotextiles in intimate contact with most natural soils will prevent them from being moved by flowing water.

PROPER FUNCTIONING OF GEOTEXTILES

In order for geotextiles to function properly in drainage and related applications, they should:

- Permit the passage of water without contributing to buildup of hydrostatic pressure.
- Prevent piping of soil particles by establishing a stable hydraulic condition in which the soil, kept in place by the more permeable fabric, maintains its structural integrity and prevents soil particles from moving through.

Actual field performance of drains constructed with geotextiles (4) confirmed the results of laboratory tests by various researchers (5). The researchers found that the percentage of soil actually trapped in meltbonded continuous filament nonwoven fabrics was quite small and did not vary significantly with soil type. The better the gradation of the soil, the smaller the amounts of fine particles that passed through the geotextile.

Results of tests conducted at Colorado State University Engineering Research Center showed that the gradations of the tested soils could determine whether the soil would control the hydraulic responses. It was determined that a soil layer satisfying the condition:

$$\frac{D_{85}}{D_{50}}, \frac{D_{50}}{D_{35}}, \frac{D_{35}}{D_{15}} < 5$$

would become a soil filter, and natural soil usually satisfies this condition.

When the soil body is not a filter, significant amounts of fine particles can be carried by water through the soil voids, and any fine opening system placed against such a soil would be made to function as a real filter that captures and accumulates the fine particles. When these systems perform as a true filter, they all will eventually be blinded by a cake of fine soil particles.

DESIGN CRITERIA

Initially little was known about uses of geotextiles as there was no long term experience with them. Decisions on how to select them were based upon results of limited trials and of laboratory evaluations. This sometimes led to incorrect or premature conclusions, e.g., a geotextile that has performed satisfactorily for certain conditions is automatically the best for every condition and should be used as the only standard for specifying geotextiles. Actually, each project should be individually studied, its performance requirements determined, and accordingly, its design criteria established to ensure successful functioning for its service life.

Sound engineering practices should be applied to each project. Careful design studies and proper construction methods help avoid mistakes and ensure satisfactory functioning of the system. Proper planning and designing should include site surveys. Soil conditions, soil quality, soil particle size distribution, and soil permeability and hydrology should be determined. In addition, one must establish functional requirements, and select the right materials for the project.

As more test and performance data are accumulated, they help engineers better understand what physical properties of geotextiles are relevant to the geotextile's performance. Such an understanding enables designers to properly select and specify geotextiles for their projects.

The U.S. Army Corps of Engineers is one of the few agencies to document results of hydraulic characteristic testing (6). Using soil types of known gradation, the Corps established guidelines for using geotextiles, indicating that selection of geotextiles should depend upon the D_{85} size of the protected soil, the EOS (equivalent opening size) and a gradient ratio. As these results were based upon tests conducted with woven filament fabrics, the design criteria for fabrics recommended by the Corps of Engineers would apply to woven but not to nonwoven fabrics, whose structures are quite different. Filtration tests were conducted for 60 hours, now considered too short a period as concluded from later tests at the University of Tennessee and at Colorado State University.

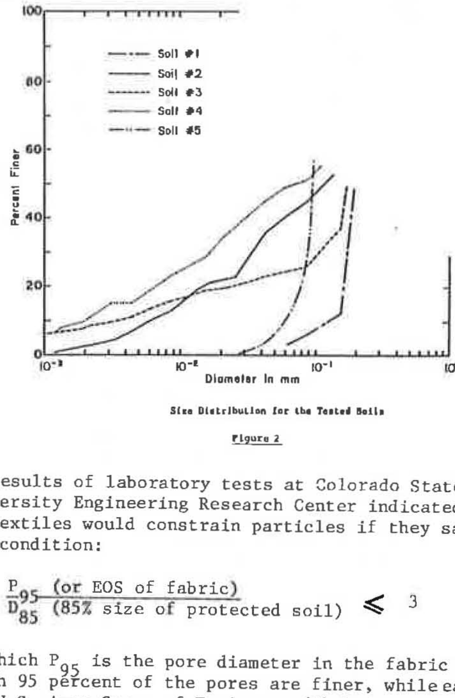
The University of Tennessee conducted tests for 21 to 28 days, or until the flow through the system became constant. Only one fabric was considered in tests using twenty soil types. The University of Tennessee researchers concluded that the design criteria of geotextiles must be the same as those established for conventional aggregate filters.

In order to broaden our understanding of the hydraulic function and performance of various geotextiles, laboratory tests were conducted at Colorado State University Engineering Research Center using five soil types with various fabrics in prolonged (800-1000 hours) permeameter tests.

The five soil types represent a variety of fine soils considered to be critical to geotextile usage by the U.S. Army Corps of Engineers and others. The soils are classified as sand, sandy loam (two), loam and loamy sand respectively, in the Triangular Soil Classification.

The soil particle size distributions for the five soils are shown in Figure 2. A different geotextile was placed within each permeameter.

Test results demonstrated that a soil layer having adequate particle size distribution can work as a filter to limit migration of fine particles within the soil. In the soil-fabric system, the soil serves as the filter and the fabric serves as a permeable constraint to prevent the soil from being moved through the fabric. As there are relatively few fine particles reaching the geotextile, the fabric will not be clogged.



Size Distribution for the Tested Soils

Figure 2

Results of laboratory tests at Colorado State University Engineering Research Center indicated that geotextiles would constrain particles if they satisfy the condition:

$$\frac{P_{95} \text{ (or EOS of fabric)}}{D_{85} \text{ (85\% size of protected soil)}} \leqslant 3$$

in which P_{95} is the pore diameter in the fabric of which 95 percent of the pores are finer, while earlier the U.S. Army Corps of Engineers (7) had suggested the ratio:

$$\frac{\text{EOS (of fabric)}}{D_{85} \text{ (of protected soil)}} < 1$$

Experimental results at Colorado State University indicated that this ratio was too restrictive as very little soil loss was observed even when the ratio

$$\frac{\text{EOS (of fabric)}}{D_{85} \text{ (of protected soil)}}$$

was varied from 0.04 to 3.82. Based on this work, a new ratio is, therefore, proposed:

$$\frac{\text{EOS (of fabric)}}{D_{85}\ \text{(of protected soil)}} < 2$$

Some geotextiles have been observed to be more effective in their ability to restrain soil particles than indicated by their EOS.

Based upon analysis of laboratory test results at Colorado State University and actual field experiences with geotextiles, the following conclusions are drawn:

- Natural soils are generally well-graded and serve as filters limiting migration of soil fines. Suitable geotextiles used with such soils work as permeable soil constraints rather than as filters and do not become clogged.
- Self-filtering soils, which are less permeable than the geotextiles, control the hydraulic responses of the systems.
- When the soil body is not a soil filter, water passing through the soil can carry significant amounts of fine particles through soil voids. Any fine opening material used with such nonfiltering soils is made to work as a real filter that can trap and accumulate fine particles. An accumulated layer of fine particles on the filter can significantly lower its permeability and can cause hydrostatic buildup.
- In these laboratory tests it was observed that for 1000 hours of continuous testing, the fabrics used had no detectable effect upon the system's hydraulics. These fabrics included a variety of constructions; woven slit films, spunbonded products and needle-punched nonwovens. Absent other design criteria, the lightest suitable fabric should be selected for lowest system cost.
- The gradient ratio developed by the U.S. Army Corps of Engineers to indicate clogging of the soil/geotextile system should be analyzed for long-term (>500 hours) rather than short-term performance. In using short-term analysis, there could be system instabilities, especially with finer soils.
- The criteria established by the U.S. Army Corps of Engineers for granular soils containing 50 percent or less by weight silt should be increased to,

$$\frac{D_{95}\ \text{(or EOS of fabric)}}{D_{85}\ \text{(of soil)}} < 2.$$

and for soils containing more than 50 percent silt, P_{95} (EOS of fabric) < opening in U.S. Standard Sieve No. 70.

The old Corps criteria may apply to systems with coarse sands and large water velocities, but fine sands containing more than 30 percent silt and/or nonswelling clay will control the system and the standard would not apply. This was shown in tests using geotextiles with a wide range of opening sizes (EOS 20 to > 200) and soils with large concentration of fines. Based upon these test results, the U.S. Army Corps of Engineers' criteria appear too restrictive and conservative.

GEOTEXTILES IN DRAINAGE AND RELATED APPLICATIONS

Engineers have successfully utilized the above design criteria for soil-water-fabric systems in assorted drainage and related applications, below.

Drainage in Pavements

In pavement structures, water drainage is usually intermittent. The drains are designed for removing water that infiltrates during rains. This water should be removed at a rate at least equal to the infiltration rate. An effective passage of water from the pavement's subbase into the drain is essential for the proper functioning of the system.

Pavements of roads, airfields, parking areas, etc. with effective drains will have longer service lives and require far less repair and maintenance than those lacking drains (7).

To be most effective, drains of flexible and rigid pavements should be installed as part of the original structure. Installing them after the pavement had badly deteriorated may not be as effective. Badly damaged subbases of pavements can no longer permit the water to steadily flow into the drain. Instead, it is pumped by traffic pressure upon the pavement and jetted through cracks and voids, carrying with it fine soil particles from the subbase and subgrade.

The functionality of drains constructed with geotextiles has been proven in hundreds of miles of highways (8).

Drains Of Earth Dams

Performance requirements for these drains are different than for pavement drains. Drains of earth dams must continually remove seepage water under far greater hydrostatic heads. Protective systems for these drains must withstand these heads and effectively prevent piping of soil particles.

Engineers have recognized the following advantages of geotextiles over graded aggregate filters:

- Geotextiles have independent tensile strength and can better resist disintegration by water.
- Geotextiles are easier to handle and install.
- A single layer of geotextiles can perform as a multi-phase graded aggregate filter.
- Geotextiles have more reliable supply and quality control.
- Geotextiles are of much lighter weight and, therefore, require less people and equipment for handling, storing, and installing them.

Early examples of geotextile uses in dams are:

- Encapsulation of toe drain and upstream lining under riprap in 1970 (9).
- Downstream drainage collector and seepage cutoff (9).

Design engineers have used the soil-water-fabric design criteria discussed earlier for the design and construction of drains in various dams. A spunbonded polypropylene geotextile was selected for:

- Chimney and blanket drains of an earth dam for the water reservoir of a fossil fuel power plant in 1977.

- Underground French drains in the downstream slope of an earth dam of a large water reservoir and as lining under riprap of the dam's entire upstream slope and at the toe of its downstream slope. The dam was built in 1978.

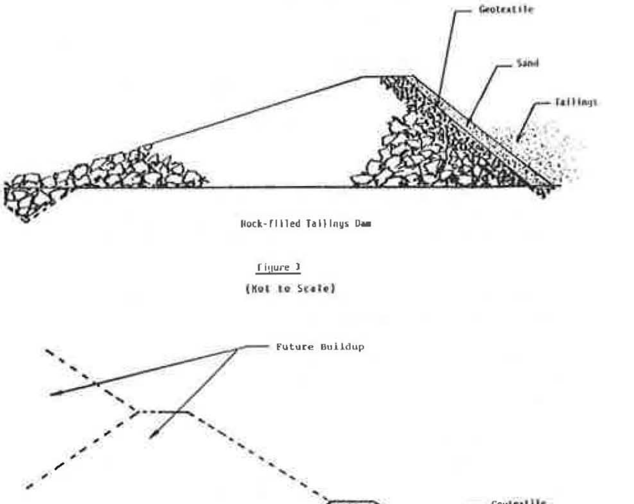
- Lining under sand of the upstream slope of a rock-filled tailings dam of a government copper mine in Chile (Figure 3) in 1981. The geotextile prevents the sand from being moved into the gravel layer of the dam.

- The blanket drain of a large starter dam for containing the tailings of a copper mine in 1981 (Figure 4). The 2km long dam will, over the years, be built to more than 90m high.

- Correcting drain systems of various dams by adding slope or toe drains to their downstream slopes without severely disturbing their existing structures.

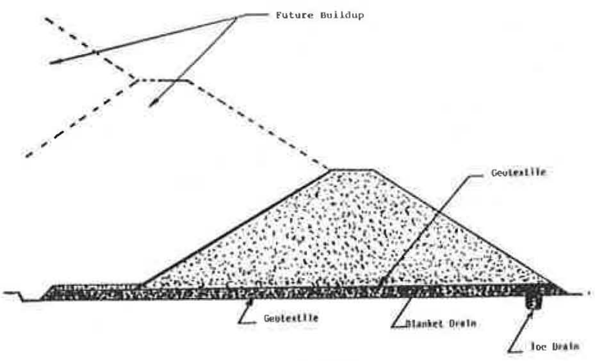
Vertical Drains

Synthetic vertical drains, also called wicks, are becoming widely accepted alternatives to vertical sand drains because they are considerably easier to install. They can better resist distortion from dynamic load stresses and reduce the risk of becoming discontinuous.



Rock-filled Tailings Dam

Figure 3
(Not to Scale)



Tailings Starter Dam

Figure 4
(Not to Scale)

Vertical drains are used to permit accelerated consolidation of wet soils by permitting water to be removed under the weight of the surcharge.

Vertical drains are expected to function under high hydrostatic pressures and should:

- Permit water to be removed from the soil at a relatively high rate without permitting soil to be removed with it.

- Not become ineffective due to distortion, clogging or degradation until the desired soil consolidation is achieved.

- Function effectively under relatively high pressures deep underground.

Intimate soil-fabric contact is virtually assured in synthetic vertical drains installed in wet soils. Their effectiveness depends upon the functionality of the sleeves around their compression-resistant plastic cores that provide passage for water squeezed into the drains. The sleeves must withstand rupturing and clogging and the cores must resist being crushed and distorted. Results of evaluations by a testing laboratory in Holland (10) led a manufacturer of synthetic vertical drains to select a spunbonded polypropylene geotextile for the sleeve of his product that has been used for various projects all over the world.

PROTECTING STREAM BANKS, LAKE AND COASTAL SHORES WITH GEOTEXTILES

The same soil-water-fabric design criteria apply as for drainage, but because water action in these applications is more severe than in drainage, there are additional functional requirements for their protective systems.

These systems should withstand, absorb and dissipate water forces. Maintaining intimate contact between the geotextile and the protected soil is essential to prevent piping and scouring of the soil.

To be effective, a riprap revetment should be heavy enough to withstand water velocity of the worst expected conditions. As the main forces of water assaulting the protective system impact from the outside, the riprap revetment is constructed of an outer belt of heavy, angular armor stones that will absorb and withstand these forces. The armor stones should interlock to better resist being moved and should have the lowest possible void volume between them to reduce the velocity of water. The voids can be reduced by filling them with smaller angular stones which interlock with the armor stones and with the fine stones of the interior zone. Such a united system would be more difficult to move than loose, individual armor stones.

An interior zone of crushed stone gravel (about 5-6 cm in diameter), or of small angular riprap (preferably smaller than 20 cm in diameter) should be placed directly on the geotextiles. This interior zone of interlocking stones, having a minimum of voids between them, will effectively dissipate the frontal assault of the water. Sometimes called a cushion blanket, it also:

- Ensures more even distribution of the weight of revetment stones on the geotextile's surface.

- Ensures better contact between the geotextile and protected soil, enabling the geotextile to better restrain the soil. This minimizes the risk of the geotextile pulsing and ballooning under water action, which can cause it to tear or make the revetment become unstable.

- Protects the geotextile against damage during placing of large, angular armor stones. This permits the use of less costly but equally effective lighter geotextiles without sacrificing the revetment's performance.

This revetment design (Figure 5) would be better than one with large, angular armor stones placed directly on the geotextile.

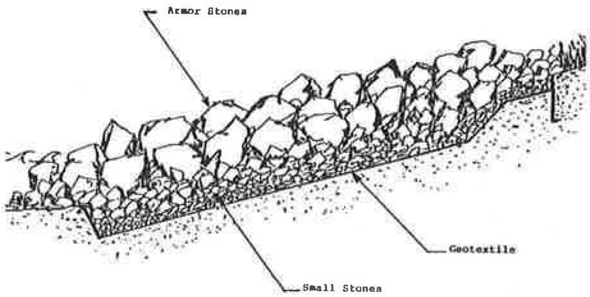
Designers should focus on the true function of geotextiles rather than become sidetracked by construction considerations. Geotextiles should keep the soil from being moved by both frontal assault and reverse flow of water.

Stones of different weights are required for different water velocities (11). The stones are more effectively used when interlocked and functioning as a united system. A good example is the use of relatively small stones kept in gabion baskets that can withstand water velocity far greater than the individual stones can withstand. Severe wave forces can damage revetments with large open areas exposed to the waves (12), even though test results had indicated the heavy individual units would be effective for the project.

In 1976-77 the New Orleans District of the U.S. Army Corps of Engineers conducted a series of tests. They evaluated the effectiveness of different geotextile structures for restraining fine Mississippi River bank soil exposed to river current and wave action generated by assorted river traffic. Bags made of different fabrics were tightly filled with the soil, and then stacked in the river under water. The effectiveness of the geotextiles was indicated by their ability to retain the soil while the bags are constantly exposed to water action of river currents and boat traffic. Bags made of a spunbonded polypropylene geotextile were found to be more effective than those of woven polypropylene because the spunbonded polypropylene geotextile structure contains a range of opening sizes that parallel more closely the particle size distribution of the protected soil. The same method might perhaps be used for evaluating geotextiles exposed to laboratory wave action.

The effectiveness of a spunbonded polypropylene geotextile for protecting soil against scouring is demonstrated in a large Dutch delta project in which millions of square meters of geotextile are used.

In order to ensure their successful performance, geotextiles should be selected with the same careful engineering, design and construction being practiced with conventional materials. Fabric performance is improved by modifying construction methods to achieve the design which will provide a properly functioning system at the lowest cost.



Revetment With Cushion Blanket
Figure 5

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