

Innovative Technology of 3D Knitted Cellular Geonets

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Abstract

Placing engineering objects (roads, embankments etc.) on low-bearing ground requires the use of geosynthetics as a reinforcement of it. Cellular geonets of three dimensional structure and honeycomb form are traditionally made from sets of perforated polyethylene straps ultrasonically bonded by spot welds. This article presents an original, innovative structure of a cellular geonet based on the technology of producing three dimensional knitted fabrics with the use of warp knitting machines with two needle bars. A 3D knitted geonet can be designed considering its three dimensional configuration and strength properties in the aspect of the anisotropic character of its structure. It was calculated that the efficiency of the knitting process of a single warp knitting machine can produce, within one month, a reinforcement for a highway 50 m wide and 5 km long using a geonet. The new technology of the cellular geonet has already been subjected to a patent application.

Key words: geotextiles, 3D knitted, cellular nets, honeycomb structure.

Introduction

New roads are very often built on poor ground, previously recognised as not suitable for building due to the low bearing capacity and high deformability thereof. Therefore such ground has to be reinforced by different methods, among which the most common are those using geosynthetics, such as cellular geonets.

Despite their main function, which is reinforcing ground by taking over and dissipating the vertical, concentrated loads, geonets transfer the pressing forces to a larger area, which reduces the unit pressure on the ground and hence decreases

the ground settlement, performing at the same time other functions such as filtration, separation, drainage and protection [1]. It should be emphasised that cellular geonets have found application not only in the stabilisation and reinforcement of ground designated for roads and highways but also airfields, retaining walls, rail and road embankments, bulwarks etc.

The traditional construction of a cellular geonet used up to this day in the road industry is a three dimensional structure in the form of a honeycomb, formed by solid, perforated or incised polyethylene bands bound by ultrasonic welding joints (Figure 1). Particular sections of the geonet are connected using plastic zip ties or staples. After unfolding, the cellular geonet is filled with various ground materials, presented in Figure 2.

The idea of the structure of a geonet and the conception of its production have already been presented by the authors at the XV International Scientific and Technological Conference – ‘Geotextiles in the building and environmental protection industries’, in May 2010 [4]. Since then it has become an inspiration for researchers working at the Department of Knitting Technology at the Technical University of Lodz to use the new, alternative technology of producing cellular geonets in a single process [5]. The idea of the new technology is based on a warp-knitting machine without needles i.e. a knitting machine on which the needles are replaced by bars of tubes specially bent – a prototype of the machine was constructed at Clemson College, or the machine produced by the Italian company Waltex in which loopers (feeder guides) in the shape of hooks interlacing two sets of warp threads are the loop forming elements. A significant characteristic of the

machines mentioned is the fact that the knitted structures obtained were reinforced with horizontal weft threads over the whole or just on a part of the width of the knitted fabric produced.

It should be highlighted that the presented technology of producing cellular geonets with the use of a new warp knitting machine without needles, with the original structure and principle of operation, as well as the highly efficient technology based on a well known warp knitting machine with two needles, is a great contribution to the new technologies of geotextiles. The authors of this article undertook a research study on the application of three dimensional knitted gratings in composite reinforcements for constructional materials used in the building and aircraft industries, among others.

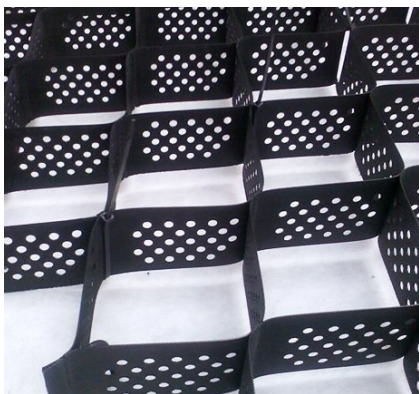


Figure 1. Cellular geonet - structure [2].



Figure 2. Cellular geonet filled with aggregate – ex ample[3].

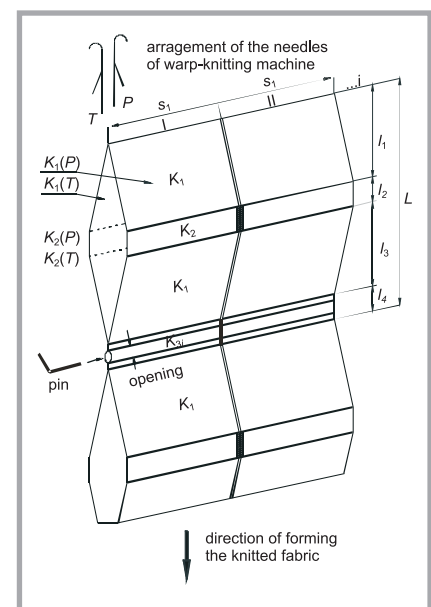


Figure 3. Model of the structure of a 3D knitted cellular geonet (patent application).

The aim of the investigations performed and design analyses presented in this article was to elaborate an innovative, highly efficient technology for producing three dimensional knitted cellular geonets using flat-knitting machines with two bars, used in manufacturing technical textiles. It was assumed that the nets would be characterised by a programmed geometry of three dimensional architecture, suitable strength properties in the aspect of their anisotropic structure and by other usability features.

Geometrical model and structure of a 3D knitted cellular geonet

A schematic structural model of a 3D knitted cellular geonet produced on a flat

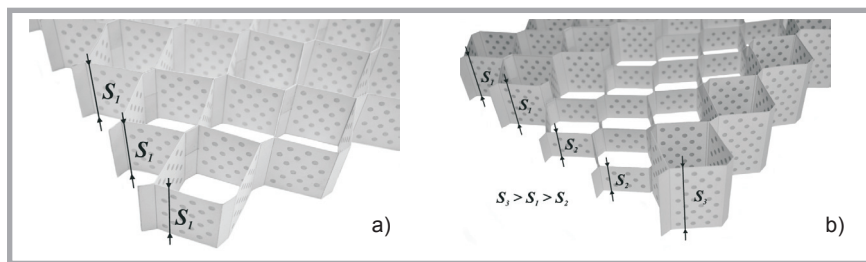


Figure 4. Structure of a cellular geonet: a) constant width (height of segments), b) variable width of segments.

warp-knitting machine with two bars is presented in Figure 3.

The geometry of the structure of a geonet can be presented in the form of a single repeating three dimensional segment of width S_i and length L_i formed by single elements or bounded

layers of knitted fabrics marked as K_i . Marks 'P' and 'T' presented in the geometrical model refer to the technology of producing geonets on warp knitting machines with two bars, where: P – a bar of front needles and T – a bar of back needles.

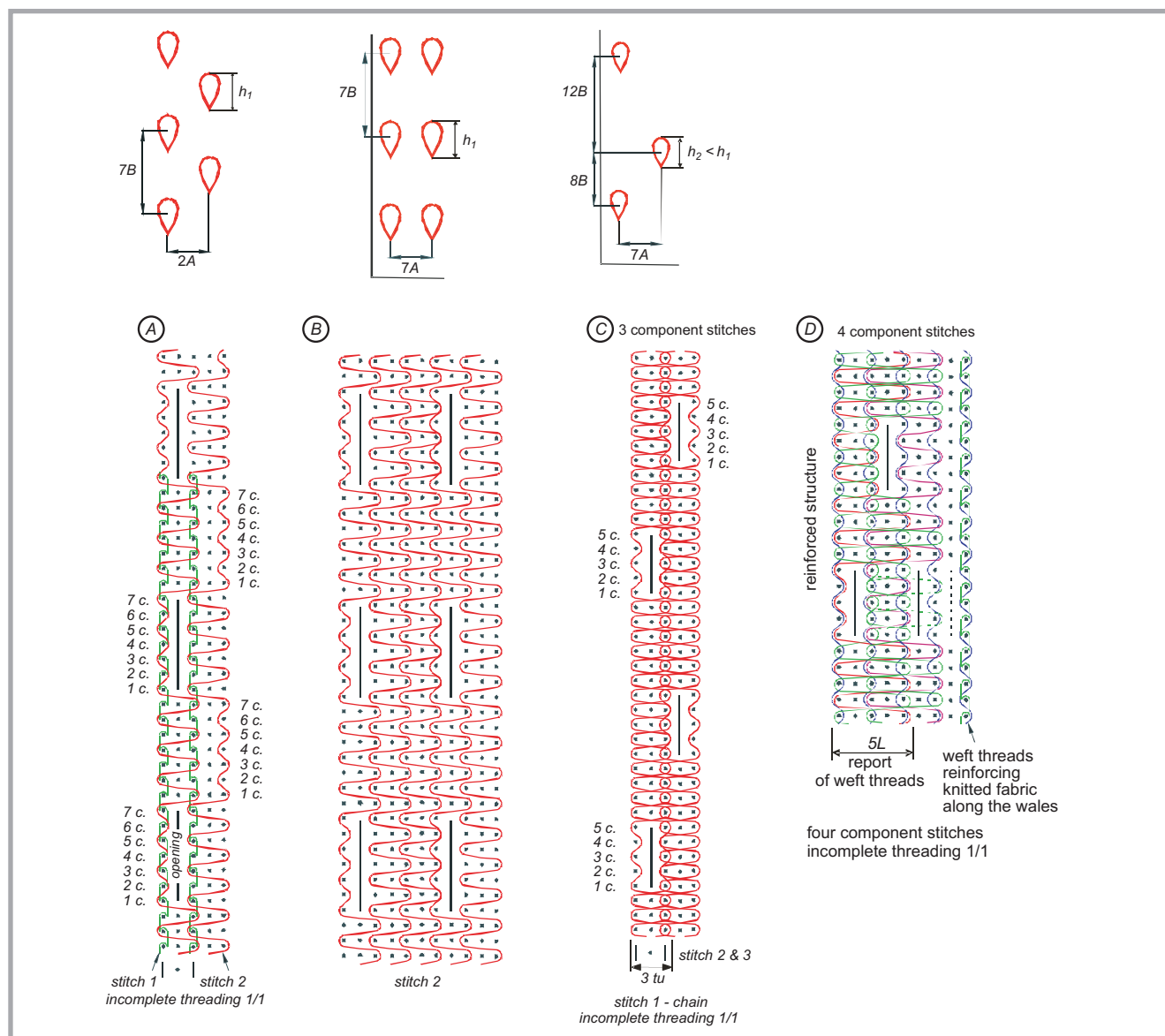


Figure 5. Structure of stitches and arrangement of openings of the knitted cellular geonet in element K1: a) alternate arrangement of openings, b) plain arrangement, c) arbitrary arrangement, d) stitch additionally reinforced with weft threads.

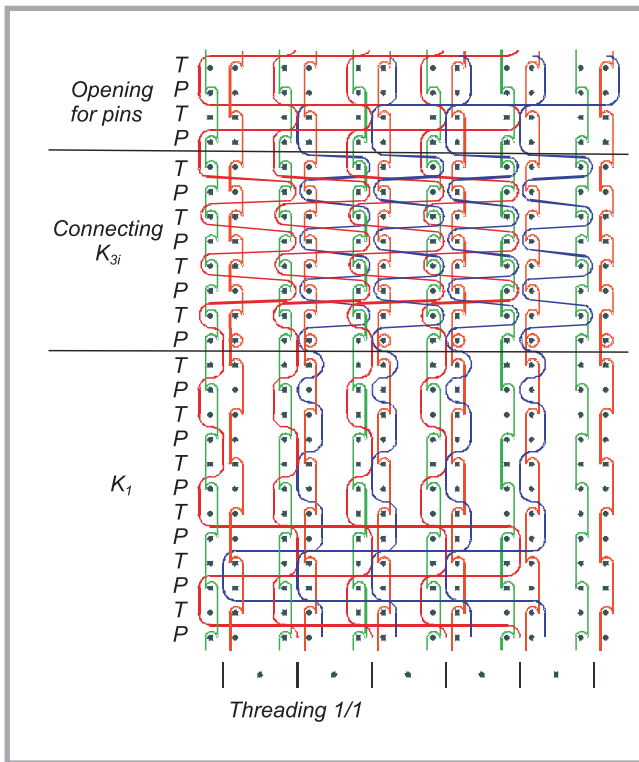


Figure 6. Structure of a stitch in elements K_{3i} (with an opening for pins), connecting the segments of a cellular geonet.

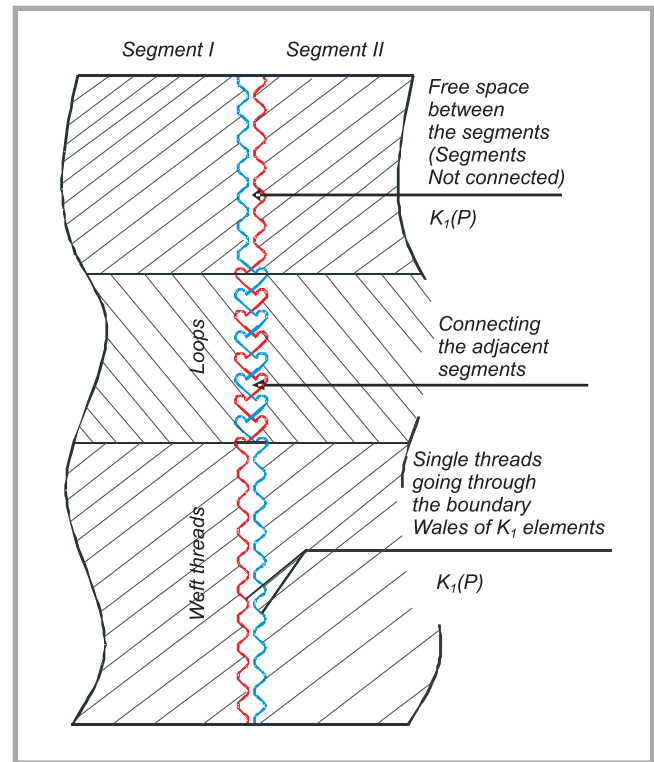


Figure 7. Connecting two adjacent segments of a 3d knitted cellular geonet.

In the technology presented the segments can be of the same or different width: $S_i = \text{const.}$ or $S_i \neq \text{const.}$ (**Figure 4**).

These different variants of the structure of a geo-grating are provided thanks to the possibility of producing a structure with geometrical and physical properties that are constant or variable.

The length of single segments L_i can be constant or variable: $L_i = \text{const.}$ or $L_i \neq \text{const.}$, while the adjacent segments in the horizontal configuration will always have the same length. Diversification of the length of segments can be undertaken on a machine, over the length of the fabric produced. The length of a segment equals that of individual elements K_i :

$$L = \sum l_i = l_1 + l_2 + l_3 + l_4 \quad (1)$$

Assuming n_j is the number of designed segments of a geonet of width S_i , the operational length of the needle bar of a warp knitting machine S_G can be evaluated using the following dependence:

$$S_G = S_1 \cdot n_1 + S_2 \cdot n_2 + \dots + S_k \cdot n_k = \sum_{i=1}^k S_i \cdot n_i \quad (2)$$

where:

- n_i – number of segments of width S_i ,
- k – summary number of groups of segments.

The basic element of a geonet segment, marked as $K1$, is a net-knitted fabric produced in a form distributed on the front and back needles of the back bed of the warp-knitting machine. In other applications of a three dimensional knitted structure, segments $K1$ can take the form of a totally built-up structure (not a net knitted structure), and they can also have a different stitch structure. Moreover, the layers of $K1(P)$ and $K1(T)$ segments produced on the opposite needle bars can be of a different structure. The structure and properties of the knitted fabric in element $K2$ enable to join the side parts of individual segments of the geonet. The $K3$ element can take a joined form or that of a tube, enabling to put the pin through, fixing the geonet to the ground. A structure of net-knitted fabric of $K1$ elements can be obtained by programming weft projections to join the wales of the chain stitch of open loops. Therefore it is possible to place the nets (clearance) arbitrarily, with respect to both their size and arrangement on the surface of the knitted fabric. Examples of such structures are presented as a scheme in **Figure 5**.

An additional characteristic of the technology of producing net-warp-knitted fabrics described is the possibility of reinforcing the structure of the knitted fabric

by adding additional weft threads, which interlace individual wales of chains. The strength of the knitted fabric can be additionally programmed by selecting an accurate width of the main threads forming the stitch of a chain and weft threads.

A schematic presentation of the stitch of the net warp-knitted fabric in the $K3i$ elements joining the segments of the 3D knitted cellular geonet is presented in **Figure 6**.

The process of connecting elements $K1$ in the area of element $K3i$ involves forming chain loops by connecting the main threads on the needles of the front (P) and back (T) beds with warp threads, and next separating the structure by forming a knitted fabric in an analogous way to the $K1$ element but without nets, in order to form an opening for a pin.

In order to obtain a 3D knitted structure produced in a flat form, the adjacent edges of $K2$ elements formed on the needles of the front and back beds of the warp knitting machine should be connected in an alternate manner, which is possible thanks to the feeding of the edge needles of both segments with weft threads previously connecting the edges of segments

in elements $K1$. The connecting process is presented in **Figure 7**.

In order to verify the innovative technique of producing the 3D knitted cellular geonets elaborated, a functional model (a prototype) of this net was made and is presented in **Figure 8**. The process of forming a knitted fabric on a warp knitting machine with two bars is explained in **Figures 8.a** and **8.b**, which present fragments of needle bars. **Figures 8.b** and **8.c** show the arrangement of segments in a partially unfolded state and **Figure 8.d** - in a completely unfolded state of the cellular geonet.

Next, after forming the geonet on the flat knitting machine with two bars, the side parts $K2$ of the individual segments were bound by thermal welding under the pressure of the knitted fabric surfaces in elements $K2$. Therefore additional coloured threads of thermoplastic polypropylene bands were incorporated into the structure of the knitted fabric of element $K2$, and therefore increase the effect of bounding, the lengths of projections of weft threads were increased, as is presented in **Figure 9**. The bounding of segments performed by bringing the polypropylene bands near the melting point and pressing down the connecting surfaces of knitted fabrics with axial forces N is presented in **Figure 10**.

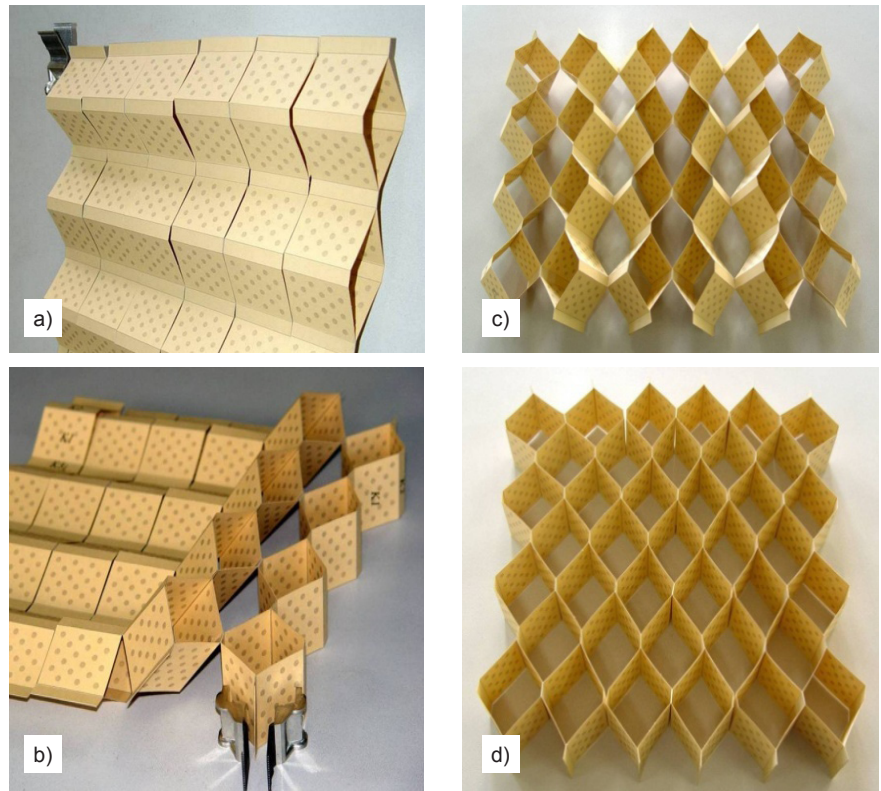


Figure 8. Prototype functional model of a cellular geonet: a) on a machine, b) and c) partially formed, d) completely formed.

Efficiency of the production process of a 3D cellular knitted geonet

In order to calculate the efficiency of the innovative technology proposed, the following assumptions were made:

- The width of a highway with the median strip, shoulders, emergency strips and slopes, which are reinforced with a cellular geonet, equals approx. 50 m, see **Figure 11** (see page 106) [6].

- dimensions (given in millimeters) of a section of a cellular geonet after unfolding: $8000 \times 2500 \times 150$,
- dimensions (given in millimeters) of a segment of a cellular geonet after unfolding: $210 \times 250 \times 150$.

The dimensions mentioned above are presented in **Figure 12** (see page 106), which illustrates in a schematic way a NEOWEB™ – NWS geonet, referring to a knitted geonet [1].

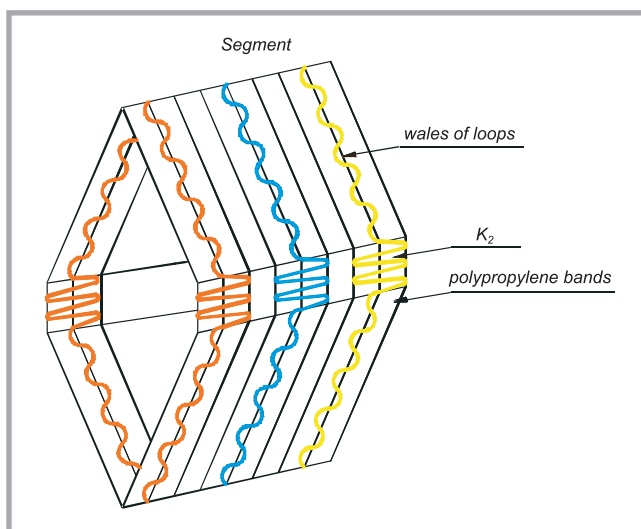


Figure 9. Incorporating weft threads from PP bands in $K2$ elements of the geonet's segments.

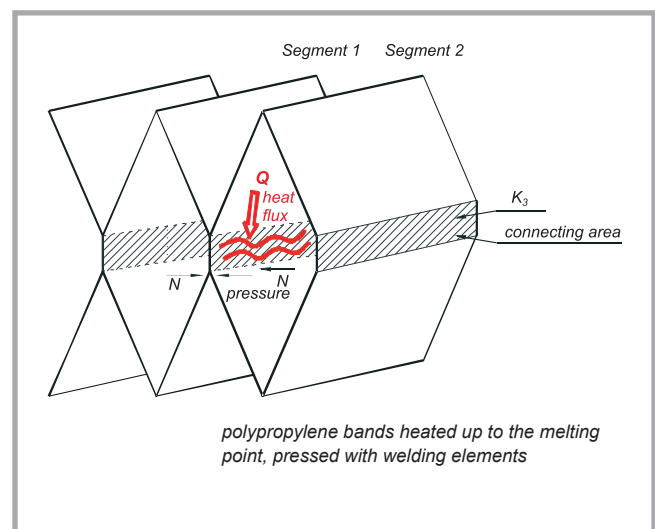


Figure 10. Connecting the segments of a 3D knitted cellular geonet; N – normal pressure of $K2$ layers of adjacent segments.



Figure 11. Example of a highway A4 with the following dimensions marked, given in meters: $[2 \cdot (\sim 7.0) + 2 \cdot 1.5 + 2 \cdot 3.0 + 4 \cdot 3.75 + (\sim 12.0)] \approx 50.0$ [6].

The number of segments within the width of one section equals:

$$8000 : 210 \approx 38 \text{ seg.} \quad (3)$$

The width of a needle bar allowing to form one section:

$$150 \text{ mm (height of geonet's segment)} \cdot 38 \text{ (segments)} = 5700 \text{ mm (224" ang.)} \quad (4)$$

Taking into consideration the rhombic configuration of side walls in a segment (**Figure 12**) after unfolding the cellular geonet, the length l_b of these walls can be calculated using the following dependence:

$$l_b = \sqrt{\left(\frac{250}{2}\right)^2 + \left(\frac{210}{2}\right)^2} = 163 \text{ m} \quad (5)$$

The length of one segment on a knitting machine, assuming that the width of elements $K2 = K3 = 30$ mm, equals:

$$2 l_b + 2 \cdot 30 = 326 + 60 = 386 \text{ mm} \quad (6)$$

Within a section length of 2.5 m, there are 10 segments in a geonet unfolded on the ground. Thus the length of knitted fabric within one section of a geonet on a knitting machine equals 3.86 m.

With the average height of a row of knitted fabric being 3.5 mm, there should be $3860 : 3.5 = 1103$ rows formed in order to obtain one section of a cellular geonet. The number of sections of a geonet necessary to reinforce the ground under the full 50 m width of dual carriageway highway equals:

$$50 : 8 = 6.25 \text{ sections} \quad (7)$$

In order to produce a 3D cellular knitted geonet, the authors used a RD6 type warp-knitting machine with two bars, and with the speed of knitting reaching 800 turns/min, made by Karl Mayer, while in order to produce one row on the needles of both bars, the main shaft of the knitting machine must perform two turns [7, 8].

The efficiency of the warp-knitting machine given in m/h equals:

$$(800 : 2) \text{ rows/min} \times 3.5 \text{ mm} = 1400 \text{ mm/min} = 84 \text{ m/h} \quad (8)$$

With the length of the geonet section being 3.86 m, we obtain:

$$84 \text{ m/h} : 3.86 \text{ m} = 21.8 \text{ section/h} \quad (9)$$

For the geonet unfolded on the ground:

$$(21.8 \text{ section/h} \times 2.5 \text{ m}) : 6.25 \text{ Section within the width of the highway} \approx 8.7 \text{ mb highway/h} \quad (10)$$

while, with the coefficient of efficiency of a warp-knitting machine $\eta = 0.9$, the real efficiency of the knitting process equals:

$$8.7 \text{ m} \times 24 \text{ h} \times 0.9 = 187.9 \text{ mb highway/24h} \quad (11)$$

and

$$187.0 \text{ mb} \times 26 \text{ days} = 4885.4 \text{ mb} \approx 4.9 \text{ km highway/month} \quad (12)$$

The analysis performed indicated that in one month one warp-knitting machine with two bars can produce a 3D cellular geonet in the amount which allows to reinforce ground for nearly 5 km of a double carriageway highway, with a full width of 50 m.

Advantages of the new textile technology for producing cellular geonets

The possibilities of designing the geometrical parameters of geonets include:

- programming the number of segments in the product (section) prepared,

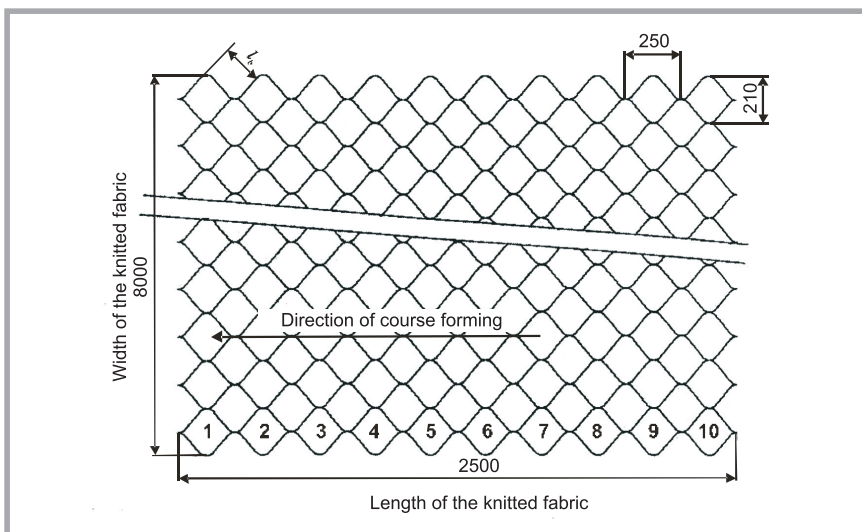


Figure 12. Dimensions of a section and segment of a NEOWEB™ - NWS geonet, with reference to a 3D knitted geonet [1].

- determining the width and length of the segments and whole section,
- creating the porosity and degree of the surface covering of side walls of the segments by selecting 'fully covered' or openwork stitches of knitted fabrics with the configuration and size of openings already determined,
- creating different structural parameters of the parallel walls of the segments,
- producing a tube-shaped knitted fabric connecting the segments, in which pins can be inserted in order to fix the cellular geonet to the ground,
- marking with colours the weft threads of the polypropylene bands of the geonet type ('coloured code').

Determining the strength parameters of geonets by:

- selecting reports of the threading of needle bars (complete or incomplete),
- selecting suitable stitches, especially the weft ones with straight segments of threads, which limit the elasticity and increase the strength and rigidity of a knitted fabric,
- selecting threads of suitable strength, elasticity modulus, linear density, structure and kind of raw material.

The use of modern, highly efficient flat warp-knitting machines with two needle bars enables to:

- manufacture products in the majority formed on a knitting machine, which require only connecting the adjacent segments (into one),
- produce one section of a standard cellular geonet of the following dimensions: 8000 × 2500, or to produce simultaneously 2, 3 or 4 smaller ones over the operating width of the warp knitting machine,
- on a machine equipped with a laminating device, to cover the geonet produced with poliurethane material or bituminous mass in order to protect the product from corrosion,
- search for other applications, such as three dimensional geonets for reinforcement of concrete constructions,
- technology with the use of a flat warp knitting machine with two bars is significantly more efficient and energy-saving than the alternative weaving technology.

The 3D knitted cellular geonet is an innovative product protected by a patent (application).

Summary and conclusions:

1. The problem of new, innovative 3D knitted structures of cellular geonets used in road construction engineering is a current and extremely important issue in the context of the present critical state of Polish roads and realisation of the national road and motorway construction program.
2. The new technologies and constructions of 3D knitted cellular geonets presented are an alternative and more beneficial solution than those obtained from polyethylene bands. The new conception of 3D knitted geotextile nets is characterised by the possibility of programming the structural parameters and three dimensional geometry of the geonet. It also enables to determine the strength of the geonet, depending on its application, and to produce geonets using highly efficient technologies.
3. 3D knitted geonets are innovative structures, hence the new technology of their production is protected by a patent application. The invention is a product of scientific research conducted at two national universities: Technical University of Lodz and University of Bielsko-Biala. The invention has a practical aspect from the point of view of applications of these kinds of nets in the road construction industry in Poland and also from that of the real possibilities of their production in Polish textile enterprises.

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