

DESCRIPTION

Support structure for the uniform distribution of loads on a straight segment and support prism for the uniform distribution of loads on a surface

Sector of the Art

The invention falls within the field of structures for the transmission of loads. The structure object of the invention is based on a fractal system and is suitable for the distribution of loads on poor soils or for aeronautical structures such as landing gear, impact shields, coupling structures on spacecraft, etc.

Background to the invention

Fractal structures are widely used in architecture as support structures due to their ability to support large surface loads by means of thin elements, as disclosed in Rian, I. M., & Sassone, M. (2014). Trene-inspired dendriforms and fractal-like branching structures in architecture: A brief historical overview. *Frontiers of Architectural Research*, 3(3), 298-323.

In addition, fractal structures represent an optimal design for elements that are subjected to pressures by uniform loads, as disclosed in Farr, R.S. (2007). Fractal design for an efficient shell strut under gentle compressive loading. *Physical Review E*, 76(5), 056608 and Farr, R.S. (2007). Fractal design for efficient brittle plates under gentle pressure loading. *Physical Review E*, 76(4), 046601.

For its part, the uniform distribution of loads on the foundations of a structure is a broad field of study, since this uniform distribution is what guarantees that the maximum pressure on the foundations is the minimum possible. For example, the documents Dems, K., & Plaut, R. H. (1990). Design of beams, plates and their elastic foundations for uniform foundation pressure. *Structural optimization*, 2(4), 213-222 and Elkelany, M. E. A. (2016) and Methods for achievement uniform stresses distribution under the foundation. *International Journal of Civil Engineering and Technology (IJCIET)* are cited.

However, no structures are known in the prior art which are capable of uniformly distributing a point load over a straight segment or over a surface, e.g. a foundation, and which can furthermore obtain the same stress value in all its constituent elements.

5 **Summary of the invention**

The problem of transmitting a specific load to a straight support segment leads to triangular structures, so that the load is applied at the upper vertex and transmitted to the two support points located at the lower vertices. If in each of these vertices we
10 locate nodes that allow rotation and arrange triangular structures whose bases are half as long as the base of the original triangle, we will have a two-level structure with four support points instead of two, all equidistant in the support, and the load will be distributed among the four support points, but not necessarily uniformly. If we repeat this process by increasing the levels indefinitely, we will have a structure with an infinite
15 number of support points, among which the load will be distributed, but not necessarily uniformly. Although this indefinite process is not possible from an engineering point of view, it is possible to have a finite number N of levels such that there is a sufficient number of support points to cover the support with support points as close as desired. The structure object of the invention has geometric and mechanical features such that
20 the load distribution is uniform.

The structure object of the invention has application, for example, in the dispersion of the load in constructions such as buildings, bridges, runways, that is, any type of constructive structure. This is useful when constructions are made on poor soils, such
25 as maritime ones, since the irregular distribution of loads can produce the uneven subsidence of the structure and its breakage.

The structure object of the invention also has application in the uniform dispersion of the energy of the impacts against the shields, optimizing them. In an exemplary
30 embodiment, the structure can be applied to the impact of space debris against space shields, defensive shields on ships, tanks, explosives, etc.

The structure object of the invention also has application in allowing an even distribution of the impact of landing gear, which allows the realization of lighter designs with the
35 consequent saving of materials in the manufacturing process and fuel in the routes.

Another example of application would also be in a parachute where the line structure would match the structure of the invention and achieve uniform load distribution over the parachute canvas.

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The structure object of the invention comprises:

- a set of bars distributed two-dimensionally and connected to each other by nodes that allow the rotation of the bars, where the bars form edges of triangles, the triangles being placed recursively according to a fractal structure, where the set of bars comprises N levels, the level N being configured to be located fixed to the straight segment, where at each node of the base of the triangle of the level n the vertex of a triangle of the level $n + 1$ is located and where:

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- o the bars of the bases of the triangles of level $n + 1$ have a length that is half the length of the bars of the bases of the triangles of level n for the levels $n = 1, 2, \dots, N - 1$,
- o inclined bars of a same level n have equal length and equal modulus J , where modulus J is equal to the cross-sectional area of the bar $\times$ longitudinal modulus of elasticity of the bar,
- o the bars of the bases of the triangles at the same level n have equal length and equal modulus J , and
- o the bars of the bases of the triangles at the different levels n have the following modulus J :

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$$\bullet \quad J_n^H = J_1^H \tan(\beta_1) \cotan(\beta_n) / 2^{n-1}, \text{ levels } n = 1, 2, \dots, N$$

where:

J_n^H is the value of the modulus J of a base bar of a level n triangle, and β_n is the angle that the inclined bars of level n form with the bars of the base.

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- a support system that meets the following characteristics:
 - o all the support points include a first fixing means of the set of bars to the segment, configured to restrict the movement of the structure in a

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direction perpendicular to the segment, where said first fixing means are arranged at the nodes of the bases of the triangles of the level N ,

- 5 ○ a support point, known as a fixed support point, includes a second means of fixing the set of bars to the segment, arranged at one of the nodes of the bases of the triangles of level N and configured to restrict the movement of the bars of the base of the structure.

10 The structure object of the invention allows to arrange a finite number N of levels such that there is a sufficient number of support points to obtain a load distribution as close to a uniform distribution as desired.

15 In this application, a bar is understood to be any element resistant to axial stress. More particularly, a rigid bar is understood to be any element resistant to tensile stress and compression and a flexible bar is understood to be any element resistant to tensile stress. An exemplary embodiment in which the structure is compressed would be the pillar of a building. An example of embodiment in which the structure is pulled would be to replace the suspension lines of a parachute with the structure object of the invention.

20 In an exemplary embodiment, the bars of the bases of the triangles generated in the level N have the same length as the bars of the bases of the triangles generated in the level $N - 1$.

25 In another embodiment, the bars of the bases of the triangles generated in the level N have a length that is half the length of the bars of the triangles generated in the level $N - 1$.

30 The parameters that completely determine the geometric shape of the structure and that are the choice of the designer are as follows:

- i) The number of levels N .
 - ii) The length R of the segment and therefore of the base of the structure.
 - iii) The angle β_n formed by the inclined bars of the level n with the base, where $n = 1, 2, \dots, N$. Note that in the construction of the successive levels it is required that the bases of the triangles meet certain conditions, but at no
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time is reference made to their height, so the angles $\beta_1, \beta_2, \dots, \beta_N$ are free parameters that allow to change the shape of the structure.

- iv) Which of all the support points is fixed in the structure.
- v) The value of the module J in each of the levels for the inclined bars of the same level.
- vi) The value J_1^H of the modulus J of the bars of the bases of the triangles of the first level.

The parameters N , R and $\beta_n, n = 1, 2, \dots, N$ mentioned above determine the lengths L_n^I and L_n^H of the inclined bars and the bars of the bases of the triangles respectively of the structure at each level n , where:

- Example of embodiment in which the bars of the bases of the triangles generated in the level N have a length that is half the length of the bars of the triangles generated in the level $N - 1$:

- inclined bars: $L_n^I = R / ((2^{n+1} - 2^{n+1-N}) \cos(\beta_n))$, for the levels $n = 1, 2, \dots, N$
- Base bars: $L_n^H = R / (2^n - 2^{n-N})$, for the levels $n = 1, 2, \dots, N$

- Example of embodiment in which the bars of the bases of the triangles generated in the level N have the same length as the bars of the bases of the triangles generated in the level $N - 1$:

- inclined bars:

- $L_n^I = R / (2^{n+1} \cos(\beta_n))$, for the levels $n = 1, 2, \dots, N - 1$
- $L_n^I = R / (2^n \cos(\beta_n))$, for the level $n = N$

- Base bars of the triangles:

- $L_n^H = R / 2^n$, for the levels $n = 1, 2, \dots, N - 1$
- $L_n^H = R / 2^{n-1}$, for the level $n = N$

However, the structure of recursive triangles needs the support system indicated above

- to provide the structure with stability from a structural point of view, which is an indispensable requirement for it to work mechanically and therefore be able to transmit any type of load.
- 5 The support system ensures that the structure does not move or rotate in any direction of the plane, thus being stable. This condition is essential to obtain a uniform load distribution in the base, but it is not enough by itself.
- As mentioned above, J denotes the resulting modulus of the product of the cross-sectional area and the longitudinal modulus of elasticity.
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- The inclined bars of a same level of the structure have the same length and are required to support the same load value. Therefore, the modulus J must be the same for all the inclined bars of the same level. However, the module J may be different for bars of
- 15 different levels. Note that each bar can be made from a different material as long as the value of its area is adapted so that the module J is the same on the same level.
- The bars of the bases of the triangles of the same level also have the same length and have to support the same load value. In addition, the relative deformation (quotient
- 20 between the total deformation of a bar and its original length) of the bars of the bases of the triangles of different levels must be identical. The relative deformation in a bar is given by the quotient between the force supporting the bar and the modulus J . Therefore, said module must be adapted to the force supported by the bar.
- 25 As indicated above, if it J_1^H is the value of the modulus J (product of the cross-sectional area and the longitudinal modulus of elasticity) of the bars of the bases of the triangles of the first level, the values J_n^H of the modulus J in the bars of the bases of the triangles of the structure at each level n must be $J_n^H = J_1^H \tan(\beta_1) \cotan(\beta_n) / 2^{n-1}$, for the levels $n = 1, 2, \dots, N$.
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- A further object of the invention is a support prism for the uniform distribution of loads on a surface, comprising a plurality of support structures as discussed above and located parallel to each other and equidistant, and further comprising a third fixing means at each node of each support structure configured to restrict the rotation of the
- 35 node about any axis in the plane of the structures.

The placement of successive recursive triangle structures according to the object of the invention in parallel and equidistant planes allows a linear load to be transmitted to a base in the form of a parallelogram. The linear load is distributed equally in the form of point loads between the successive structures, which transmit each point load to their supports in a uniform manner.

BRIEF DESCRIPTION OF THE DRAWINGS

To complete the description being made and aid in the understanding of the features of the invention, the present description is accompanied by a set of drawings which form an integral part of the description and where, for purposes of illustration and in a non-limiting sense, the following is shown:

Figure 1 shows a schematic view of a first embodiment of the bar assembly of the three-level support structure.

Figure 2 shows a schematic view of a second embodiment of the bar assembly of the three-level support structure.

Figure 3 shows a schematic view of the first example of realization of the bars and nodes of the bases of the lower level N together with the means of fixing said nodes to the surface.

Figure 4 shows a schematic view of the second embodiment of the bars and nodes of the bases of the lower level N together with the means of fixing said nodes to the surface.

Figure 5 shows a schematic perspective view of an example of embodiment of the support prism for the uniform distribution of loads on a surface.

Figure 6 shows a schematic perspective view of an example of embodiment of the support prism for the uniform distribution of loads on a surface together with the means of fixing said nodes to the surface.

Preferred embodiment of the invention

A three-level recursive triangle structure is shown in the figures.

- 5 Figure 1 represents an example of a three-level embodiment of the support structure for the uniform distribution of loads on a straight segment (10). The bars (1) of the base belong to the level $n = N$ and the upper node belongs to the level $n = 0$. The inclined bars (1) of levels 1, 2 and 3 form angles of inclination β_1 , β_2 and β_3 respectively.
- 10 Thus, the bars (1) of each level n form an angle β_n with the plane of the base of the triangle.

As represented in figures 1 to 4, the structure comprises:

- 15 - a set of bars (1) distributed two-dimensionally and connected to each other by nodes (2) that allow the rotation of the bars (1), where the bars (1) form edges of triangles, the triangles being placed recursively according to a fractal structure, where the set of bars (1) comprises N levels, the level N being configured to be located fixed to the straight segment (10), where in each node (2) of the base of the triangle of level the vertex of a triangle of level is located $nn + 1$ and where:

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- the bars (1) of the bases of the level triangles $n + 1$ have a length that is half the length of the bars (1) of the triangles of level n , for the $n = 1, 2, \dots, N - 1$,
 - the inclined bars (1) of a same level n have equal length and equal modulus J , where the modulus J is equal to the cross-sectional area of the bar (1) x longitudinal modulus of elasticity of the bar (1),
 - the bars (1) of the bases of the triangle at the same level n have the same length and the same modulus J , and
 - the bars (1) of the bases of the triangles at the different levels n have the following modulus J :
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$$\bullet \quad J_n^H = J_1^H \tan(\beta_1) \cotan(\beta_n) / 2^{n-1}, \quad \text{in the levels } n = 1, 2, \dots, N$$

- 35 where:

J_n^H is the value of the modulus J of a bar (1) at the base of a triangle of level n , and

5 β_n is the angle formed by the inclined bars (1) of level n with the bars (2) of the base.

A support system that meets the following characteristics:

- 10 - all the support points include a first fixing means (3) of the set of bars (1) to the segment (10), configured to restrict the movement of the structure perpendicular to the segment (10), where said first fixing means (3) are arranged at the nodes (2) of the bases of the triangles of level N ,
- 15 - a support point, known as a fixed support point, includes a second fixing means (4) of the set of bars (1) to the segment (10), arranged on one of the nodes (2) of the bases of the triangles of level N and configured to restrict the movement in the direction of the bars (1) of the base of the triangle.

20 In an exemplary embodiment, the bars (1) of the bases of the triangles on the level $N - 1$ have the same length as the bars (1) of the bases of the triangles on the level N . This embodiment is represented in figure 2.

In another embodiment, the bars (1) of the bases of the triangles of level N have a length that is half the length of the bars (2) of the bases of the triangles of level $N - 1$.
25 This embodiment is represented in figure 1.

The module J may be different for bars (1) of different levels. Note that each bar (1) can be made from a different material as long as the value of its area is adapted so that the module J is the same on the same level.

30 Therefore, any bar (1) of the structure can be made from a different material as long as the value of its area conforms to the longitudinal modulus of elasticity E of the material, so as to obtain a uniform distribution in the base. Any bar (1) of the structure can be made from a different material as long as the value of its area conforms to the
35 longitudinal modulus of elasticity E of the material in order to obtain an even distribution

in the base. However, this would cause said bar (1) not to withstand the same tension as the others.

5 The object of the invention is also a support prism for the uniform distribution of loads on a surface, comprising a plurality of support structures as discussed above and located parallel to each other and equidistant. The nodes (2) of the bases of the triangles of level N further comprise a third fixing means at each node (2) of each support structure configured to restrict the rotation of the node (2) according to any axis in the plane of the structure.

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In these structures, the height is equal in all of them and the length of the base R of all the support structures, i.e. of the support segment (10), is equal in all of them so that the point loads are distributed in segments of equal length and guarantee obtaining a uniform load distribution in the parallelogram. In addition, they must have the same number of levels N and the number of support points of the structures must be identical.

15 In addition, in the event that the structure is subjected to compression, the inclined bars (1) must be rigid, that is, they will be elements resistant to tensile and compressive stresses and the bars (1) of the bases of the triangles will be rigid or flexible, any element resistant to tensile stress being flexible.

20 In the event that the structure is subjected to traction, the inclined bars (1) will be rigid or flexible and the bars (1) of the bases of the triangles will be rigid.

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CLAIMS

1.- Support structure for the uniform distribution of loads on a straight segment (10), characterized in that it comprises:

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- a set of bars (1) distributed two-dimensionally and connected to each other by nodes (2) that allow the rotation of the bars (1), where the bars (1) form edges of triangles, the triangles being placed recursively according to a fractal structure, where the set of bars (1) comprises N levels, the level N being configured to be located fixed to the straight segment (10), where in each node (2) of the base of the triangle of level n the vertex of a triangle of level $n + 1$ is located and where:

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 - o the bars (1) of the bases of the triangles of level $n + 1$ have a length that is half the length of the bars (1) of the bases of the triangles of level n , for the levels $n = 1, 2, \dots, N - 1$,
 - o the inclined bars (1) of a same level n have equal length and equal modulus J , where the modulus J is equal to the cross-sectional area of the bar (1) x longitudinal modulus of elasticity of the bar (1),
 - o the bars (1) of the bases of the triangles at the same level n have equal length and equal modulus J , and
 - o the bars (1) of the bases of the triangles at the different levels n have the following modulus J :

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 - $J_n^H = J_1^H \tan(\beta_1) \cotan(\beta_n) / 2^{n-1}$, for the levels $n = 1, 2, \dots, N$

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where:

J_n^H is the value of the modulus J of a bar (1) at the base of a triangle of level n , and

30 β_n is the angle formed by the inclined bars (1) of level n with the bars (2) of the base,
 - a first fixing means (3) of the set of bars (1) to the segment (10), configured to restrict the movement of the structure in the direction perpendicular to the segment (10), wherein said first fixing means (3) are arranged at the nodes (2)
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of the bases of the triangles of level N ,

- a second fixing means (4) of the set of bars (1) to the segment (10) arranged at one of the nodes (2) of the bases of the triangles of level N and configured to restrict the movement in the direction of the bars (1) of the base of the structure.

2.- Support structure for the uniform distribution of loads on a straight segment (10), according to claim 1, characterized in that the bars (1) of the bases of the triangles on the level $N - 1$ have the same length as the bars (1) of the bases of the triangles on the level N .

3.- Support structure for the uniform distribution of loads on a straight segment (10), according to claim 1, characterized in that the bars (1) of the bases of the triangles on the level N have a length that is half the length of the bars (1) of the bases of the triangles on the level $N - 1$.

4.- Support structure for the uniform distribution of loads on a straight segment (10), according to any one of the preceding claims, characterised in that the structure is subjected to compression and the inclined bars (1) are rigid and the bars (1) of the bases of the triangles are rigid or flexible.

5.- Support structure for the uniform distribution of loads on a straight segment (10), as claimed in any one of the preceding claims 1 to 3, characterized in that the structure is subjected to traction and the inclined bars (1) are rigid or flexible and the bars (1) of the bases of the triangles are rigid.

6.- Support prism for the uniform distribution of loads on a surface, comprising a plurality of support structures according to any one of the preceding claims located parallel to each other and equidistant and further comprising a third fixing means at each node (2) of each support structure configured to restrict the rotation of the node (2) about any axis of the plane of the support structure.

7.- Support prism for the uniform distribution of loads on a surface, according to claim 6, wherein the plurality of support structures have the same height.

8.- Support prism for the uniform distribution of loads on a surface, according to claim 6 or 7, where the bases of the level N of all the support structures have the same length.