



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
30.05.2012 Bulletin 2012/22

(51) Int Cl.:
E01F 8/00 (2006.01)

(21) Application number: **11190856.2**

(22) Date of filing: **25.11.2011**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

- **Caniato, Marco**
31015 CONEGLIANO (IT)
- **Pasqualin Stefano**
31020 SAN POLO DI PIAVE (IT)
- **Sartor, Leo**
31044 MONTEBELLUNA (IT)

(30) Priority: **25.11.2010 IT TV20100150**

(74) Representative: **Jorio, Paolo et al**
Studio Torta S.p.A.
Via Viotti, 9
10121 Torino (IT)

(71) Applicant: **Fracasso S.p.A.**
30032 Fiesso d'Artico (VE) (IT)

(72) Inventors:
• **Bettarello, federica**
45100 ROVIGO (IT)

(54) **Acoustic panel for noise barriers and noise barrier provided with such a panel**

(57) An acoustic panel (1) characterized by comprising: a reverberating plate (6) having, on one of the two faces, a stepped-profile surface (6a) which is dimensioned so as to reflect in a "diffused" manner at least one incident acoustic wave with a predetermined reference frequency; and a layer of sound-absorbent material (7)

which is coupled to the reverberating plate (6) so as to cover the stepped-profile surface (6a), and so as to be crossed in "diffused" manner by the acoustic wave reflected by said stepped-profile surface (6a); the profile of the stepped-profile surface (6a) being determined on the basis of the "Quadratic Residue" mathematical model.

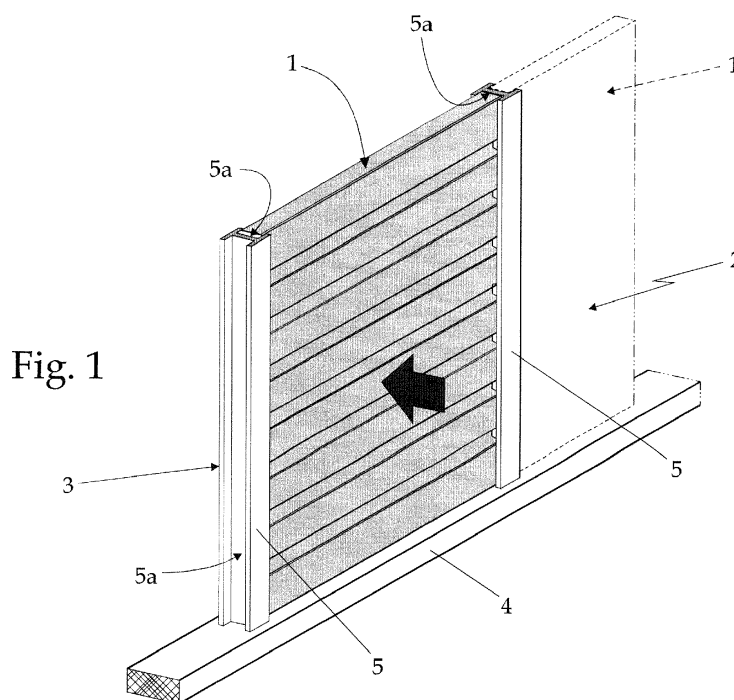


Fig. 1

Description

[0001] The present invention relates to an acoustic panel for noise barriers and to a noise barrier provided with such a panel.

[0002] More in detail, the present invention relates to a sound-absorbent acoustic panel for noise barriers adapted to obstruct the propagation of polluting acoustic waves in open spaces, to which use explicit reference will be made in the following description without therefore losing in generality.

[0003] As known, the propagation of polluting acoustic waves in open spaces, such as sections of highways or railways, construction sites or industrial plants, is normally controlled by a series of acoustic panels of substantially rectangular shape, which are mounted side-by-side on a specific support frame so as to form a substantially vertical wall, which generally in seamless manner surrounds the polluting acoustic source.

[0004] The most common sound-absorbent acoustic panels have a rectangular shape and are generally essentially formed by two rigid half-shells made of metallic material, which are essentially shaped as a shallow rectangular bowl and which are reciprocally coupled so as to form a box-like containment of flat parallelepiped shape; and by a layer of rock or glass wool, which completely fills the interspace inside the box-like container.

[0005] The outer box-like container mainly performs a sound-proofing action, while the filling material mainly performs a sound-absorbent action.

[0006] The main drawback of the acoustic panels described above is that of not being adaptable, or rather "tuned", to the features of the polluting acoustic wave, i.e. to the frequency spectrum of the incident acoustic wave, so as to maximize the shielding capacity of the noise barrier.

[0007] The features of the polluting acoustic wave indeed vary according to the type of polluting acoustic source (moving motor vehicles, moving trains, operating machinery etc.), while in the above-described acoustic panels the attenuation curve of the incident acoustic wave according to frequency has a substantially bell/wave shape which offers very narrow possibility of adjustment/adaptation.

[0008] Experimental tests have indeed shown that major variations of acoustic panel size and/or constructive materials produce only minor variations to the incident acoustic wave attenuation curve pattern.

[0009] It is the object of the present invention to make an acoustic panel for noise barriers which offers a better possibility of adapting to the features of the incident acoustic wave and which is additionally cost-effective to produce.

[0010] In accordance with such objectives, in conformity to the present invention, an acoustic panel for noise barriers is made as disclosed in claim 1 and preferably, but not necessarily, in any one of the dependent claims.

[0011] According to the invention, a noise barrier is

further made as disclosed in claim 16.

[0012] The present invention will now be described with reference to the accompanying drawings, which illustrate a non-limitative embodiment thereof, in which:

- figure 1 shows an axonometric view, with parts removed for clarity, of a noise barrier comprising acoustic panels made according to the dictates of the present invention;
- figure 2 is an exploded perspective view of one of the acoustic panels shown in figure 1;
- figure 3 is a section view of the upper part of the acoustic panels shown in figure 2; while
- figures 4, 5, 6 and 7 show on enlarged scale four different diffusion profiles which may be adopted on the front face of the reverberating plate of the acoustic panel shown in figures 2 and 3.

[0013] With reference to figures 1, 2 and 3, numeral 1 indicates as a whole a sound-absorbent acoustic panel, particularly suited for making a noise barrier 2 adapted to obstruct the propagation of polluting acoustic waves in open or closed spaces.

[0014] In the illustrated example, in particular, the noise barrier 2 is preferably, but not necessarily constituted by a series of acoustic panels 1 of preferably, but not necessarily rectangular shape, which are arranged side-by-side on a support frame 3, so as to form a preferably, but not necessarily vertical shielding frame.

[0015] More in detail, with reference to figure 1, in the illustrated example, the support frame 3 preferably, but not necessarily consists of a base 4 made preferably, but not necessarily of reinforced concrete, and by at least one pair of vertical supporting uprights 5, which overhangingly extend from the base 4 itself, parallel and mutually side-by-side. Each acoustic panel 1 is arranged straddling two consecutive vertical uprights 5 so as to have one of the two faces facing the source of the polluting acoustic waves.

[0016] In the illustrated example, in particular, the vertical uprights 5 of the support frame 3 preferably, but not necessarily consist of a series of rectilinear metallic profiles 5 with H-shape cross section, which overhangingly extend from the base 4 in vertical direction, and are arranged in pairs parallel and mutually side-by-side, so as to have the longitudinal grooves 5a locally and substantially coplanar with the laying plane of the acoustic panel 1, which is positioned straddling the rectilinear metallic profiles 5 themselves. Furthermore, the rectilinear metallic profiles 5, which form each pair of vertical uprights 5, are reciprocally distanced so that the two vertical side edges of the corresponding central acoustic panel 1 engage the longitudinal grooves 5a of the rectilinear metallic profiles 5 themselves.

[0017] With reference to figures 2 and 3, the acoustic panel 1 has, as mentioned, a preferably, but not necessarily rectangular shape and essentially consists of a reverberating plate 6 of preferably, but not necessarily rec-

tangular shape, which is made of a rigid, compact material having a nominal density higher than 200 kg/m^3 (kilograms per cubic meter), and which has, on one of the two faces, a stepped-profile surface 6a, which is dimensioned so as to reflect at least one incident acoustic wave with predetermined reference frequency or "band center" in "diffused" manner and with destructive interference; and by a layer 7 of sound-absorbent material, which has a peripheral edge that essentially follows the shape of the reverberating plate 6, and is coupled to the reverberating plate 6 so as to completely cover the stepped-profile surface 6a, so as to be crossed by the acoustic wave reflected in "diffused" manner by such a surface.

[0018] In other words, the stepped-profile surface 6a is dimensioned to "diffuse" acoustic waves of frequency and intensity different from the incident acoustic wave in all directions; such diffused waves may also cause a destructive interference with the other acoustic waves arriving towards the panel. By virtue of the two combined phenomena, a reduction of the acoustic wave amplitude is obtained.

[0019] Such a physical phenomenon is radially different from the reflection which occurs on the surface of traditional acoustic panels and is not sufficiently appreciable (in terms of reflected sound energy reduction) in presence of a constant, repetitive panel surface morphology pattern. A monotonous repetition of the "fretting" of the surface of the panel indeed reflects only one frequency, and thus the phenomenon of the diffusion distributed in frequency and of the destructive inference would be drastically reduced.

[0020] Instead, the layer 7 of sound-absorbent material systematically attenuates the intensity of the reflected acoustic waves working in parallel to the "diffused reflection with destructive interference" phenomenon because it can work for the entire length of the layer itself; the diffusion indeed "distributes" the waves in all directions after the impact of the direct wave, causing a much longer return path (and thus more effective sound-absorption) within the layer itself.

[0021] In the illustrated example, in particular, the shape of the stepped-profile surface 6a is determined on the basis of the "Quadratic Residue" or "Schroeder's" mathematical model, which was developed by mathematician Manfred SCHROEDER.

[0022] In other words, the number of steps, the width of each step and the distances between the various steps are determined on the bases of the "Quadratic Residue" or "Schroeder's" mathematical model, so as to reflect in "diffused" manner with destructive interference at least one incident acoustic wave having a reference frequency or predetermined "band center".

[0023] In the illustrated example, in particular, the reverberating plate 6 has a thickness preferably, but not necessarily comprised between 4 and 50 cm (centimetres), and a nominal density preferably, but not necessarily comprised between 300 and 8000 kg/m^3 (kilograms per cubic meter); while the stepped-profile surface

6a is preferably, but not necessarily shaped so as to copy a Schroeder profile optimized to reflect at least one acoustic wave having reference frequency or "band center" preferably, but not necessarily comprised between 500 and 4000 Hz (Hertz) in "diffused" manner.

[0024] More in detail, the stepped-profile surface 6a of the reverberating plate 6 is preferably, but not necessarily optimized according to the "Quadratic Residue" mathematical model, so as to reflect in "diffused" manner at least one first acoustic wave with reference frequency or "band center" preferably, but not necessarily equal to 500 Hz, 1000 Hz, 2000 Hz, or 4000 Hz; and at least one second acoustic wave with reference frequency or "band center" different from that of the first acoustic wave, and preferably, but not necessarily equal to 500 Hz, 1000 Hz, 2000 Hz, or 4000 Hz.

[0025] The layer 7 of sound-absorbent material has instead a nominal thickness preferably, but not necessarily comprised between 1 and 50 centimetres, and is made with a sound-absorbent material having a nominal density preferably, but not necessarily comprised between 5 and 150 kg/m^3 (kilograms per cubic meter). Such sound-absorbent material further has a porosity preferably, but not necessarily higher than 0.9; and/or a resistivity of the air flow preferably, but not necessarily comprised between 1 and 100 KN/s/m^4 ; and/or an acoustic path greater than 1.

[0026] With reference to figures 2 and 3, the acoustic panel 1 is further preferably, but not necessarily provided with an outer protective half-shell 8 substantially rigid, which is shaped so as to be fitted on the body of the reverberating plate 6, over the sound-absorbent material layer 7, so as to form an interspace which accommodates and at the same time maintains the sound-absorbent material layer 7 abutting on the stepped-profile surface 6a of the reverberating plate 6.

[0027] Furthermore, preferably, but not necessarily, in the illustrated example, the portion of the protective half-shell 8 which is faced/aligned to the stepped-profile surface 6a of the reverberating plate 6, is appropriately pierced so as to make a series of Helmholtz resonators along with the interspace which accommodates the layer 7 made of sound-absorbent material.

[0028] With reference to figures 2 and 3, in the illustrated example, in particular, the reverberating plate 6 has preferably, but not necessarily a normal thickness comprised between 10 and 25 cm (centimetres) and is preferably, but not necessarily made of cement, metal, marble or other compact high density material.

[0029] The shape of the stepped-profile surface 6a of the reverberating plate 6 is instead preferably, but not necessarily optimized on the basis of the "Quadratic Residue" mathematical model so as to be able to reflect two different incident acoustic waves in "diffused" manner. The reference frequency or "band center" of the first incident acoustic wave is preferably, but not necessarily equal to 1000 Hz (Hertz), while the reference frequency or "band center" of the second incident acoustic wave is

preferably, but not necessarily equal to 2000 Hz (Hertz).

[0030] Furthermore, in the illustrated example, the reverberating plate 6 preferably, but not necessarily consists of a series of modular reverberating boards or panels 9 of preferably, but not necessarily elongated rectangular shape (two in the illustrated example), which are fixed sideways to one another so as to form single, substantially rigid, indeformable flat body 6. The front face of the reverberating boards or panels 9 is obviously stepped-profiled so to form the stepped-profile surface of the "Quadratic Residue" mathematical model 6a on a same face of the flat body 6.

[0031] More in detail, with reference to figure 2, in the example shown, each reverberating panel 9 preferably, but not necessarily consists of a containment basin or framework 10 of elongated regular shape, which has a bottom shaped so as to copy, at least in part, the surface of the stepped-profile surface 6a of the reverberating plate 6, and of a filling core 11, made of concrete, which completely fills the containment basin or framework 10.

[0032] Preferably, but not necessarily, the reverberating panel 9 may further also comprise a stiffening armature (not shown), either completely or partially embedded in the filling core 11.

[0033] The containment basin or formwork 10 may be made either of plastic, metal or composite material. In the first case, the containment basin or formwork 10 may be advantageously made either by means of an injection molding procedure or by means of thermoforming of a sheet of plastic material of suitable thickness. In the second case, instead, the containment basin or formwork 10 may be advantageously made by means of a cold molding procedure starting from a sheet of suitable thickness.

[0034] Obviously, the reverberating plate 6 may be also formed by only one reverberating panel 9 made preferably, but not necessarily with the methods described above.

[0035] With reference to figures 2 and 3, the layer 7 of sound-absorbent material has instead a thickness preferably, but not necessarily comprised between 3 and 15 centimetres, and is made preferably, but not necessarily of open cell polyurethane foam with nominal density preferably, but not necessarily comprised between 30 and 60 kg/m³, or other cell material, preferably, but not necessarily open, with sound-absorbent properties.

[0036] Alternatively, the sound-absorbent material layer 7 made also be made of mineral fiber, either synthetic or natural, with nominal density preferably, but not necessarily comprised between 15 and 45 kg/m³.

[0037] With reference to figures 2 and 3, in the illustrated example, the protective half-shell 8 is instead preferably, but not necessarily made of metal material and essentially consists of a rectangular basin 8 dimensioned to be fitted on the reverberating plate 6. Obviously, the protective half-shell 8 may be made of plastic or composite material.

[0038] The bottom of such a basin 8 is further provided with a multitude of through holes so as to form a series

of Helmholtz resonators when the basin 8 is coupled to the reverberating plate 6.

[0039] The protective half-shell 8 may be advantageously made by means of a cold molding procedure starting from a flat or fretted plate of suitable thickness.

[0040] Instead, as mentioned, the shape of the reverberating plate 6 with stepped-profile surface 6a is determined on the basis of "Schroeder's" mathematical model, and in the illustrated example consists of an elementary diffusion profile which is repeated cyclically substantially along the entire face of the reverberating plate 6.

[0041] With reference to figures from 4 to 7, if dimensioned to reflect only one incident acoustic wave with predetermined reference frequency or "band center" in "diffused" manner, the steps which form the elementary diffusion profile have all the same width and spatial distribution, which is determined directly by "Schroeder's" mathematical model.

[0042] More in detail, according to "Schroeder's" mathematical model, in order to reflect the sound in "diffused" manner, the profile of the surface must copy the mathematical sequence QRS so as to obtain diffusers having diffraction lobes with the same energy, operating with propagation waves of flat type. The mathematic sequence QRS is given by the ratio:

$$s_n = n^2 \bmod(N)$$

where n is number of sequence of steps, and N is a prime number, the choice of which is bound to the modularity of the panels, as described below.

[0043] The size of the "steps" (width w and height d_n) which form the various diffusers are determined by means of mathematical ratios:

$$w = \lambda_{\min} / 2$$

and

$$d_n = \frac{s_n \lambda_0}{2N}$$

where $\lambda_{\min}$ is the minimum design wavelength, and λ_0 is the maximum design wavelength (the two frequencies must not necessarily have the same value).

[0044] Obviously, the lower the reference frequency or "band center", the higher will be the overall size of the diffuser in terms of both length and thickness needed to

reflect the incident acoustic wave in "diffused" manner.

[0045] Thus, having chosen the reference frequency or "band center", and consequently the corresponding minimum wavelength $\lambda_{\min}$, and having fixed the maximum length L that the elementary diffusion profile must have, the maximum number of steps n_s which form the elementary diffusion profile is obtained on the basis of the equation:

$$n_s = \frac{L}{w}$$

[0046] For determining the steps the prime number N closest to n_s is considered, and from this the sequence s_n is then determined by means of the first formula shown above.

[0047] If instead it must be dimensioned to reflect incident acoustic waves which have two different reference frequencies or "band centers" (see figures 2 and 3) in "diffused" manner, the steps which form the elementary diffusion profile generally have a mutually different length, and the spatial distribution of the steps is determined by combining to each other the two elementary diffusion profiles determined directly by "Schroeder's" mathematical model with reference to the two required reference frequencies or "band center".

[0048] More in detail, the elementary diffusion profile dimensioned to reflect incident acoustic waves with two different reference frequencies or "band center" in "diffused" manner may be obtained by combining the sequence of the widths of the steps formed by "Schroeder's" mathematical model with reference to the first reference frequency or "band center" with the sequence of distances or heights between the tops of the various steps provided with "Schroeder's" mathematical model with reference to the second reference frequency or "band center".

[0049] In other words, a single reference frequency or "band center" is fixed to determine the width of the step (w), and then the various heights of the steps are calculated according to the different frequency values (d_j). Alternatively, it is also possible to use a single reference frequency or "band center" for calculating the sequence of the step heights (d) and determine the different widths of the steps (w_j) according to different reference frequency or "band center" values.

[0050] In the illustrated example, in particular, having decided to maintain the width of the reverberating panel 9 equal to 100 cm (centimeters), a maximum number of steps equal to 6 result for each elementary diffusion profile "tuned" to a single reference frequency or "band center", therefore the QRS sequence which is obtained (for $N=7$) is the following: $sn=\{0, 1, 4, 2, 2, 4, 1\}$.

[0051] Furthermore, in order to dimension the reverberating panel 9 to work in the typical road and railway traffic frequency spectrum, and since the dimensional

limit fixed for the thickness of the reverberating plate 6 (for example 10 cm) cannot be exceeded, a sequence of steps of variable width and fixed height has been chosen.

[0052] In the case of an elementary diffusion profile "tuned" onto two different reference frequencies or "band centers", the same dimensional constraints require choosing a number of steps equal to 12.

[0053] Figure 4, for example, shows an elementary diffusion profile optimized to reflect the incident acoustic waves with reference frequency or "band center" equal to approximately 1000 Hz (Hertz) in "diffused" manner.

[0054] Such an elementary diffusion profile preferably, but not necessarily consists of 6 steps, each of which has a length l_1 equal to approximately 17 cm (centimeters). Consequently, the first elementary diffusion profile has a total width l_0 preferably, but not necessarily equal to 102 cm (centimeters).

[0055] In this first elementary diffusion profile, the flat top of the first step a_1 lays on the reference plane P of the profile, while the flat top of the second step a_2 is positioned behind (under) the reference plane P , at a distance d_2 from the flat top of the first step a_1 preferably, but not necessarily equal to approximately 2.45 cm (centimeters). The flat top of the third step a_3 is instead positioned in front of (over) the reference plate P , at a distance d_3 from the flat top of the second step a_2 preferably, but not necessarily equal to approximately 9.8 cm (centimeters).

[0056] The flat top of the fourth step a_4 is still positioned in front of the reference plane P , but closer to the reference plane P than the flat top of the third step a_3 , and is at a distance d_4 from the flat top of the fourth step a_3 preferably, but not necessarily equal to 4.9 cm (centimeters).

[0057] The flat top of the fifth step a_5 is still positioned in front of the reference plane P , but closer to the reference plane P than the flat top of the fourth step a_4 , and is at a distance d_5 from the flat top of the fourth step a_4 preferably, but not necessarily equal to 4.9 cm (centimeters).

[0058] The flat top of the sixth and last step a_6 is instead positioned behind the reference plane P , at a distance d_6 from the flat top of the fifth step a_5 preferably, but not necessarily equal to approximately 9.8 cm (centimeters).

[0059] In the case of an elementary diffusion profile optimized to reflect the acoustic waves with frequency equal to 2000 Hz (Hertz) in "diffused" manner, the nominal length 11 of each step should be equal to approximately 9.5 cm (centimeters), while the total length 10 of the diffusion profile should be equal to approximately 54 cm (centimeters).

[0060] With regards instead to the distance between the flat tops of the various steps, the distance d_2 between the flat top of the second step a_2 and the second flat of the first step a_1 should be equal to approximately 1.23 cm (centimeters); the distance d_3 between the flat top of

the third step a3 and the flat top of the second step a2 should be equal to approximately 4.9 cm (centimeter); the distance d_4 between the flat top of the fourth step a4 and the flat top of the third step a3 should be equal to approximately 2.45 cm (centimeters); the distance d_5 between the flat top of the fifth step a5 and the flat top of the fourth step a4 should be equal to approximately 2.45 cm (centimeters); while the distance d_6 between the flat top of the sixth step a6 and the flat top of the fifth step a5 should be equal to approximately 4.9 cm (centimeters).

[0061] More in general, the six-step elementary diffusion profile described above may be used to reflect an incident acoustic wave with reference frequency or "band center" different from 1000 Hz (Hertz) in "diffused" manner, taking the measure of decreasing the nominal widths of the steps and the distances between the flat tops of the various steps in manner reversely proportional to the ratio between the old reference frequency or "band center" (1000 Hz) and the new reference frequency or "band center" of the incident acoustic wave which is reflected in "diffused" manner, leaving substantially unchanged the dimensional ratios between the various portions of the elementary six-step diffusion profile.

[0062] Obviously, the elementary diffusion profile could have a number of steps higher than six, providing that the nominal width of the steps and the distances between the various steps comply with the "Quadratic Residue" mathematical model.

[0063] Figure 5, instead, shows a second elementary diffusion profile optimized to reflect the incident acoustic waves with reference frequency or "band center" equal to approximately 1000 Hz (Hertz) in "diffused" manner, and with reference frequency or "band center" equal to approximately 2000 Hz (Hertz).

[0064] Such a second elementary profile preferably, but not necessarily consists of 12 steps of different length from each other, and has a total width f_0 preferably, but not necessarily equal to approximately 100.2 cm (centimeter).

[0065] In this second elementary diffusion profile, the flat top of the first step c1 has a width f_1 equal to approximately 15.5 cm (centimeters) and lays on a reference plane P of the profile, while the flat top of the second step c2 has a width f_2 equal to approximately 5.4 cm (centimeters) and is positioned in front (over) the reference plane P, at a distance h_2 from the top of the first step c1 equal to approximately 1.23 cm (centimeters).

[0066] Instead, the flat top of the third step c3 has a width f_3 equal to approximately 4.3 cm (centimeters) and lays behind (under) the reference plane P of the profile, at a distance h_3 from the flat top of the second step c2 equal to approximately 4.9 cm (centimeters).

[0067] Furthermore, the flat top of the fourth step c4 has a width f_4 equal to approximately 3.4 cm (centimeters) and lays behind (under) the reference plane P of the profile, but closer to the reference plane P than the flat top of the third step c3, at a distance h_4 from the flat

top of the third step c3 equal to approximately 2.45 cm (centimeters).

[0068] Furthermore, the flat top of the fifth step c5 has a width f_5 equal to approximately 2.7 cm (centimeters) and lays behind (under) the reference plane P of the profile, but closer to the reference plane P than the flat top of the fourth step c4, at a distance h_5 from the flat top of the fourth step c4 equal to approximately 2.45 cm (centimeters).

[0069] The flat top of the sixth step c6 has instead a width f_6 equal to approximately 2.1 cm (centimeters) and lays in front of (over) the reference plane P of the profile, at a distance h_6 from the flat top of the fifth step c5 equal to approximately 4.9 cm (centimeters).

[0070] The flat top of the seventh step c7 has instead a width f_7 equal to approximately 30.9 cm (centimeters) and lays substantially on the reference plane P of the profile, at a distance h_7 from the flat top of the sixth step c6 equal to approximately 1.23 cm (centimeters).

[0071] The flat top of the eighth step c8 has instead a width f_8 equal to approximately 10.7 cm (centimeters) and lays in front of (over) the reference plane P of the profile, at a distance h_8 from the flat top of the seventh step c7 equal to approximately 1.23 cm (centimeters).

[0072] The flat top of the ninth step c9 has instead a width f_9 equal to approximately 8.6 cm (centimeters) and lays behind (under) the reference plane P of the profile, at a distance h_9 from the flat top of the eighth step c8 equal to approximately 4.9 cm (centimeters).

[0073] Furthermore, the flat top of the tenth step c10 has a width f_{10} equal to approximately 6.9 cm (centimeters) and lays behind (under) the reference plane P of the profile, but closer to the reference plane P than the flat top of the ninth step c9, at a distance h_{10} from the flat top of the ninth step c9 equal to approximately 2.45 cm (centimeters).

[0074] Instead, the flat top of the eleventh step c11 has a width f_{11} equal to approximately 5.4 cm (centimeters) and lays behind (under) the reference plane P of the profile, but further from the reference plane P than the flat top of the tenth step c10, at a distance h_{11} from the flat top of the tenth step c10 equal to approximately 2.45 cm (centimeters).

[0075] Finally, the flat top of the twelfth step c12 has a width f_{12} equal to approximately 4.3 cm (centimeters) and lays in front of (over) the reference plane P of the profile, at a distance h_{12} from the flat top of the eleventh step c11 equal to approximately 4.9 cm (centimeters).

[0076] Figure 6, instead, shows a third elementary diffusion profile optimized to reflect the incident acoustic waves with reference frequency or "band center" equal to approximately 1000 Hz (Hertz) in "diffused" manner, and with reference frequency or "band center" equal to approximately 2000 Hz (Hertz). Such a third elementary profile again consists of 12 steps of mutually different length, and has a total width w_0 preferably, but not necessarily equal to approximately 100.2 cm (centimeters).

[0077] In this third elementary diffusion profile, the flat

top of the first step e1 has a width w_1 equal to approximately 30.9 cm (centimeters) and lays on a reference plane P of the profile, while the flat top of the second step e2 has a width w_2 equal to approximately 10.7 cm (centimeters) and is positioned in front (over) the reference plane P, at a distance k_2 from the flat top of the first step e1 equal to approximately 2.45 cm (centimeters).

[0078] The flat top of the third step e3 has instead a width w_3 equal to approximately 8.6 cm (centimeters) and lays behind (under) the reference plane P of the profile, at a distance k_3 from the flat top of the second step e2 equal to approximately 9.8 cm (centimeters).

[0079] Furthermore, the flat top of the fourth step e4 has a width w_4 equal to approximately 6.9 cm (centimeters) and lays behind (under) the reference plane P of the profile, but closer to the reference plane P than the flat top of the third step e3, at a distance k_4 from the flat top of the third step e3 equal to approximately 4.9 cm (centimeters).

[0080] Instead, the flat top of the fifth step e5 has a width w_5 equal to approximately 5.4 cm (centimeters) and lays behind (under) the reference plane P of the profile, but closer to the reference plane P than the flat top of the fourth step e4, at a distance k_5 from the flat top of the fourth step e4 equal to approximately 4.9 cm (centimeters).

[0081] The flat top of the sixth step e6 has instead a width w_6 equal to approximately 4.3 cm (centimeters) and lays in front of (over) the reference plane P of the profile, at a distance k_6 from the flat top of the fifth step e5 equal to approximately 9.8 cm (centimeters).

[0082] Instead, the flat top of the seventh step e7 has a width w_7 equal to approximately 15.5 cm (centimeters) and lays substantially on the reference plane P of the profile, at a distance k_7 from the flat top of the sixth step e6 equal to approximately 2.45 cm (centimeters).

[0083] The flat top of the eighth step e8 has instead a width w_8 equal to approximately 5.4 cm (centimeters) and lays in front of (over) the reference plane P of the profile, at a distance k_8 from the flat top of the seventh step e7 equal to approximately 1.23 cm (centimeters).

[0084] Instead, the flat top of the ninth step e9 has a width w_9 equal to approximately 4.3 cm (centimeters) and lays behind (under) the reference plane P of the profile, at a distance k_9 from the flat top of the eighth step e8 equal to approximately 4.9 cm (centimeters).

[0085] Instead, the flat top of the tenth step e10 has a width w_{10} equal to approximately 3.4 cm (centimeters) and lays behind (under) the reference plane P of the profile, but closer to the reference plane P than the flat top of the ninth step e9, at a distance k_{10} from the flat top of the ninth step e9 equal to approximately 2.45 cm (centimeters).

[0086] Instead, the flat top of the eleventh step e₁₁ has a width w_{11} equal to approximately 2.7 cm (centimeters) and lays behind (under) the reference plane P of the profile, but further from the reference plane P than the flat top of the tenth step e10, at a distance k_{11} from the flat

top of the tenth step e10 equal to approximately 2.45 cm (centimeters).

[0087] Finally, the flat top of the twelfth step e12 has a width w_{12} equal to approximately 2.1 cm (centimeters) and lays in front of (over) the reference plane P of the profile, at a distance k_{12} from the flat top of the eleventh step e11 equal to approximately 4.9 cm (centimeters).

[0088] Finally, figure 7 shows a fourth elementary diffusion profile optimized to reflect the incident acoustic waves with reference frequency or "band center" equal to approximately 2000 Hz (Hertz) in "diffused" manner, and with reference frequency or "band center" equal to approximately 4000 Hz (Hertz). Also this fourth elementary diffusion profile consists of 12 steps which, in this case, have length alternatively equal to approximately 9 cm (centimeters) or approximately 4 cm (centimeters), and has a total length m_0 preferably, but not necessarily equal to approximately 78 cm (centimeters).

[0089] In this fourth elementary diffusion profile, the flat top of the first step b1 has a width m_1 equal to approximately 9 cm (centimeters) and lays on a reference plane P of the profile, while the flat top of the second step b2 has a width m_2 equal to approximately 4 cm (centimeters) and is positioned behind (under) the reference plane P, at a distance g_2 from the top of the first step b1 equal to approximately 1.23 cm (centimeters).

[0090] The flat top of the third step b3 has a width m_3 equal to approximately 9 cm (centimeters) and lays behind (under) the reference plane P of the profile, but closer to the reference plane P than the flat top of the second step b2, at a distance g_3 from the flat top of the second step b2 equal to approximately 0.61 cm (centimeters).

[0091] Furthermore, the flat top of the fourth step b4 has a width m_4 equal to approximately 4 cm (centimeters) and lays behind (under) the reference plane P of the profile, but closer to the reference plane P than the flat top of the third step b3, at a distance g_4 from the flat top of the third step b3 equal to approximately 4.9 cm (centimeters).

[0092] Instead, the flat top of the fifth step b5 has a width m_5 equal to approximately 9 cm (centimeters) and lays behind (under) the reference plane P of the profile, but closer to the reference plane P than the flat top of the fourth step b4, at a distance g_5 from the flat top of the fourth step b4 equal to approximately 2.45 cm (centimeters).

[0093] Instead, the flat top of the sixth step b6 has a width m_6 equal to approximately 4 cm (centimeters) and lays behind (under) the reference plane P of the profile, but more distant from the reference plane P than the flat top of the fifth step b5, at a distance g_6 from the flat top of the fifth step b5 equal to approximately 2.45 cm (centimeters).

[0094] The flat top of the seventh step b7 has a width m_7 equal to approximately 9 cm (centimeters) and lays behind (under) the reference plane P of the profile, but closer to the reference plane P than the flat top of the sixth step b6, at a distance g_7 from the flat top of the sixth

step b6 equal to approximately 1.23 cm (centimeters).

[0095] Instead, the flat top of the eighth step b8 has a width m_8 equal to approximately 4 cm (centimeters) and lays behind (under) the reference plane P of the profile, but further from the reference plane P than the flat top of the seventh step b7, at a distance g_8 from the flat top of the seventh step b7 equal to approximately 2.45 cm (centimeters).

[0096] Instead, the flat top of the ninth step b9 has a width m_9 equal to approximately 9 cm (centimeters) and lays behind (under) the reference plane P of the profile, but further from the reference plane P than the flat top of the eighth step b8, at a distance g_9 from the flat top of the eighth step b8 equal to approximately 1.23 cm (centimeters).

[0097] Instead, the flat top of the tenth step b10 has a width m_{10} equal to approximately 4 cm (centimeters) and lays in front of (over) the reference plane P of the profile, at a distance g_{10} from the flat top of the ninth step b9 equal to approximately 4.9 cm (centimeters).

[0098] The flat top of the eleventh step b11 has instead a width m_{11} equal to approximately 9 cm (centimeters) and lays behind (under) the reference plane P of the profile, at a distance g_{11} from the flat top of the second step b10 equal to approximately 2.45 cm (centimeters).

[0099] Finally, the flat top of the twelfth step b12 has a width m_{12} equal to approximately 4 cm (centimeters) and lays in front of (over) the reference plane P of the profile, at a distance g_{12} from the flat top of the eleventh step b11 equal to approximately 1.23 cm (centimeters).

[0100] The operation of the acoustic panel 1 may be easily inferred from the description above, and thus does not require further explanations except for specifying that in order to obstruct the propagation of the incident acoustic wave, the acoustic panel 1 must be arranged so that the stepped-profile surface 6a of the reverberating plate 6 faces the polluting acoustic source.

[0101] The acoustic concepts on which the "Quadratic Residue" or "Schroeder's" mathematical model are based are extensively described in many scientific papers and publications and do not therefore require further explanations.

[0102] The principles and algorithms underlying the "Quadratic Residue" or "Schroeder's" mathematical model, as some applications of such a mathematical model, are described in detail in the paper entitled "Diffuse Sound Reflection By Maximum-Length Sequence" written by M.R. Schroeder and published in the "Journal of Acoustic Society of America", 57 (pages 149-150) in 1975, and in the book entitled "Concert Hall Acoustics" written by Y. Ando and published by Springer, Berlin-New York in 1985. The contents of these two publications are intended as incorporated in the present patent application for sake of greater completeness.

[0103] Instead, with regards to the assembly of the acoustic panel 1, the reverberating panel or panels 9 forming the reverberating plate 6 are suited to be made directly on-site, by casting the concrete directly into the

containment basins or formworks 10, where provided, after having positioned stiffening armatures inside the containment basins or formworks 10.

[0104] The bottom of the various containment basins or formworks 10 is obviously shaped so as to follow at least one part of the stepped-profile surface 6a of the reverberating plate 6a. In other words, the shape of the bottom of the containment basins or formworks 10 consists of one of the elementary diffusion profiles described above, which is cyclically repeated substantially along the entire bottom of the containment basins or formworks 10.

[0105] After the concrete has completely hardened in the containment basins or formworks 10, forming the filling core 11, the construction of the acoustic panel 1 consists in fixing, if needed, the reverberating panels 9 sideways with respect to one another so as to form the reverberating plate 6; and then positioning the layer 7 of sound-absorbent material on the resulting reverberating plate 6 to cover the respective surface with a stepped-profile surface 6a.

[0106] The construction of the sound-absorbent panel 1 is then concluded by positioning the protective half-shell 8 on the body of the reverberating plate 6, over the sound-absorbent material layer 7, and subsequently anchoring the protective half-shell 8 onto the body of the reverberating plate 6, so as to block and press the sound-absorbent material layer 7 stably abutting onto the surface of with the stepped-profile surface 6a of the reverberating plate 6.

[0107] Possibly, the construction of the acoustic panel 1 may also include removing the containment basins or formworks 10 from the reverberating panel 9 before composing the reverberating plate 6, or before positioning the sound-absorbent material layer 7 to cover the stepped-profile surface 6a of the reverberating plate 6.

[0108] In this case, the reverberating plate 6 will be formed by one or more filling cores 11 made of concrete, fixed sideways to one another.

[0109] There are many advantages deriving from the particular structure of the acoustic panel 1.

[0110] Experimental tests have shown that the combined use of a reverberating plate 6 provided with a stepped-profile surface 6a made according to the "Quadratic Residue" or "Schroeder's" mathematical model and of a layer of sound-absorbent material 7 to cover the surface of the stepped-profile surface 6a, allows to make acoustic panels 1 which have a shielding capacity much higher than that of the acoustic panels of noise barriers currently in use.

[0111] In other words, the synergetic effect between "diffused reflection with destructive interference" implemented by the stepped-profile surface 6a and the systematic attenuation of the sound-absorbent material layer 7 allows to block the propagation of acoustic waves in a much more effective manner than the acoustic panels for noise barriers currently in use.

[0112] Furthermore, by appropriately shaping the

stepped-profile surface 6a of the reverberating plate 6 it is possible to optimize the performance of the acoustic panel 1 and of the noise barrier 2 according to the frequency spectrum of the acoustic waves emitted by the polluting acoustic source to be shielded.

[0113] It is finally apparent that the construction of the reverberating panel 9 on-site considerably reduces the installation costs of the noise barrier 2.

[0114] It is finally apparent that changes and variants can be made to the acoustic panel 1 and noise barrier 2 described and shown above without departing from the scope of protection of the present invention.

Claims

1. An acoustic panel (1) **characterized by** comprising: a reverberating plate (6) having, on one of the two faces, a stepped-profile surface (6a) which is dimensioned so as to reflect in a "diffused" manner at least one incident acoustic wave with a predetermined reference frequency; and a layer of sound-absorbent material (7) which is coupled to the reverberating plate (6) so as to cover the stepped-profile surface (6a), and so as to be crossed by the acoustic wave reflected in "diffused" manner by said stepped-profile surface (6a).
2. An acoustic panel according to Claim 1, **characterized in that** the profile of the stepped-profile surface (6a) of the reverberating plate (6) is determined on the basis of the "Quadratic Residue" mathematical model.
3. An acoustic panel according to Claim 1 or 2, **characterized in that** the reverberating plate (6) has a nominal density over 200 kg/m³.
4. An acoustic panel according to Claim 1, 2 or 3, **characterized in that** the layer of sound-absorbent material (7) has a nominal density ranging between 5 and 150 kg/m³.
5. An acoustic panel according to any one of the preceding claims, **characterized by** also comprising an outer protective half-shell (8) which is fitted on the body of the reverberating plate (6), over the layer of sound-absorbent material (7), so as to form an interspace that houses and maintains said layer of sound-absorbent material (7) in abutment against the stepped-profile surface (6a) of said reverberating plate (6).
6. An acoustic panel according to Claim 5, **characterized in that** the protective half-shell (8) portion that is faced/aligned to the stepped-profile surface (6a) of the reverberating plate (6), is pierced.
7. An acoustic panel according to any one of the preceding claims, **characterized in that** the shape of stepped-profile surface (6a) is determined on the basis of the "Quadratic Residue" mathematical model, so as to reflect in a "diffused" manner at least two incident acoustic waves with different reference frequency from one another.
8. An acoustic panel according to Claim 7, **characterized in that** the reference frequency of the first and/or second incident acoustic wave is 500 Hz, 1000 Hz, 2000 Hz, or 4000 Hz.
9. An acoustic panel according to any one of the preceding claims, **characterized in that** the shape of the stepped-profile surface (6a) comprises an elementary diffusion profile that is cyclically repeated along the face of the reverberating plate (6).
10. An acoustic panel according to Claim 9, **characterized in that** said elementary diffusion profile comprises 6 or 12 steps.
11. An acoustic panel according to Claim 5 or 6, **characterized in that** the protective half-shell (8) is made of metal material.
12. An acoustic panel according to Claim 3, **characterized in that** the reverberating plate (6) is made of concrete.
13. An acoustic panel according to any one of the preceding claims, **characterized in that** the reverberating plate (6) is formed by one or more reverberating panels (9) which are fixed sideways to one another, so as to form a substantially rigid, flat body (6); the front face of said reverberating panels (9) being stepped shaped so as to form/compose, on a same face of said flat body (6), the stepped-profile surface (6a) of said reverberating plate (6).
14. An acoustic panel according to Claim 13, **characterized in that** said reverberating panel (9) comprises a containment basin or formwork (10) whose bottom is shaped so as to follow at least a part of the stepped-profile surface (6a) of the reverberating plate (6), and a concrete filling core (11) that completely fills the containment basin or formwork (10).
15. An acoustic panel according to Claim 14, **characterized in that** the containment basin or formwork (10) is made of plastic, metal or composite material.
16. A noise barrier (2) comprising a support frame (3) and a sequence of acoustic panels (1) which are arranged, on said support frame (3), one side by side the other so as to form a shielding wall; the noise barrier (2) being **characterized in that** at least one

of said acoustic panels (1) is made according to any one of Claims from 1 to 15.

5

10

15

20

25

30

35

40

45

50

55

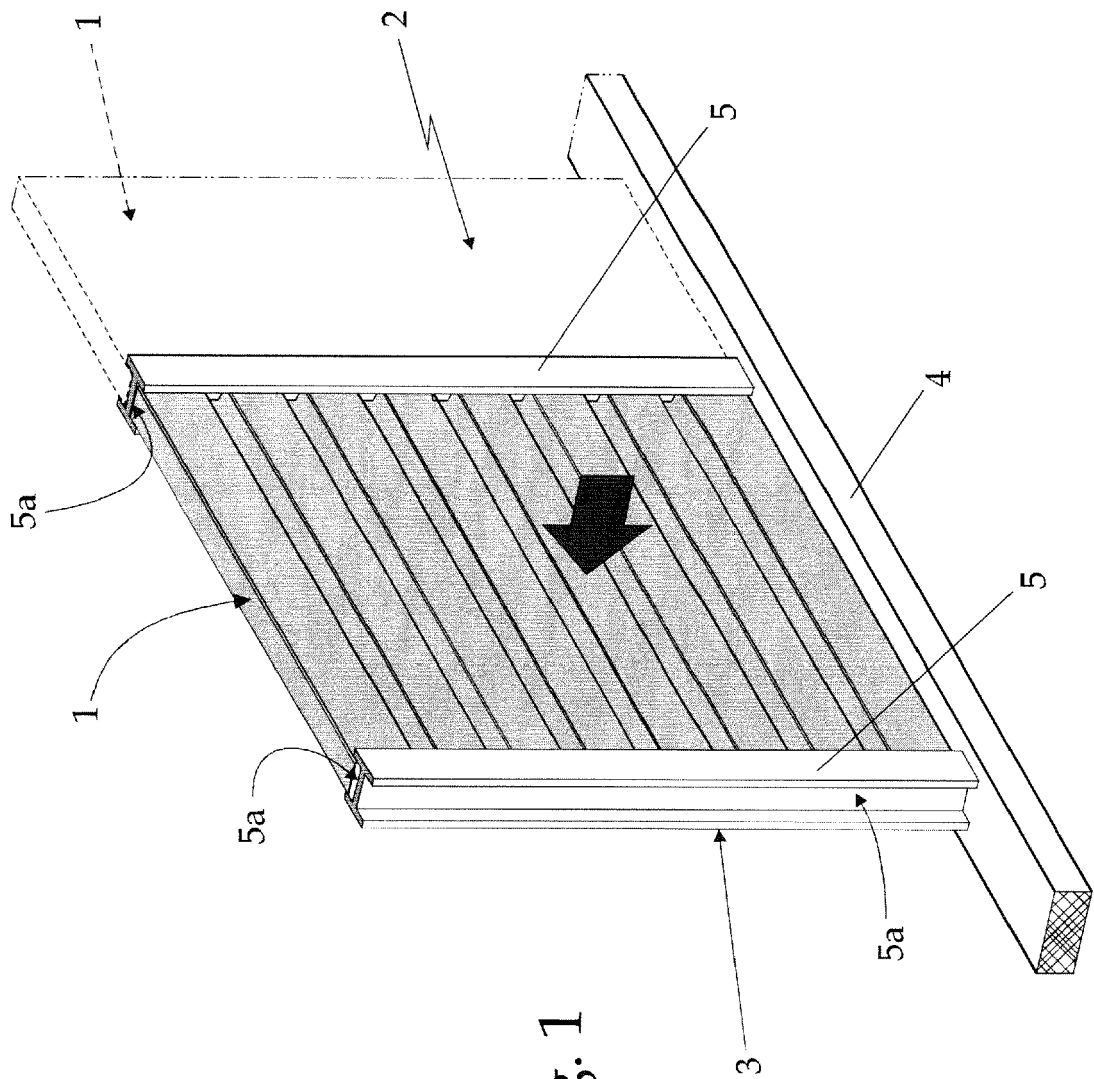


Fig. 1

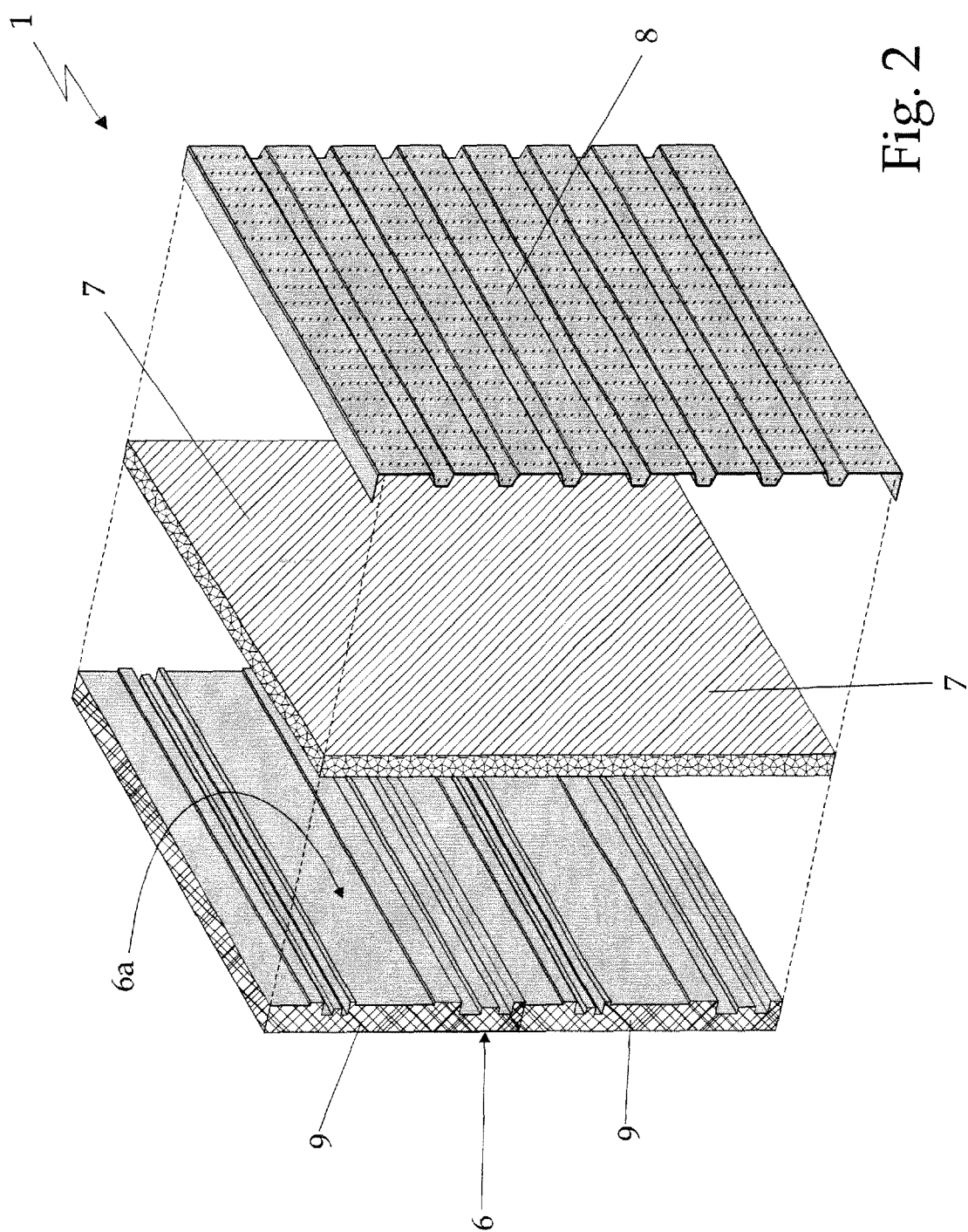
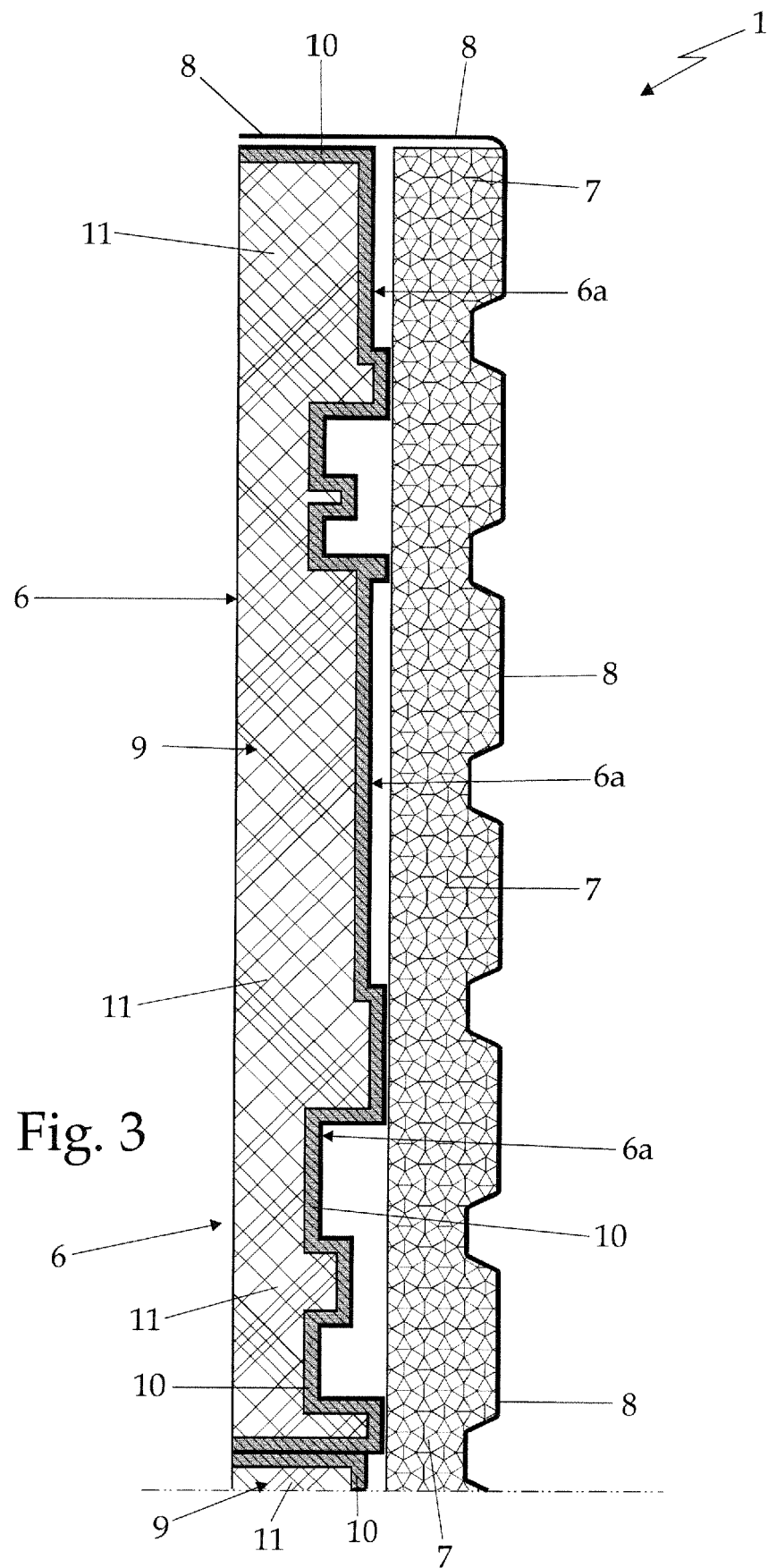


Fig. 2



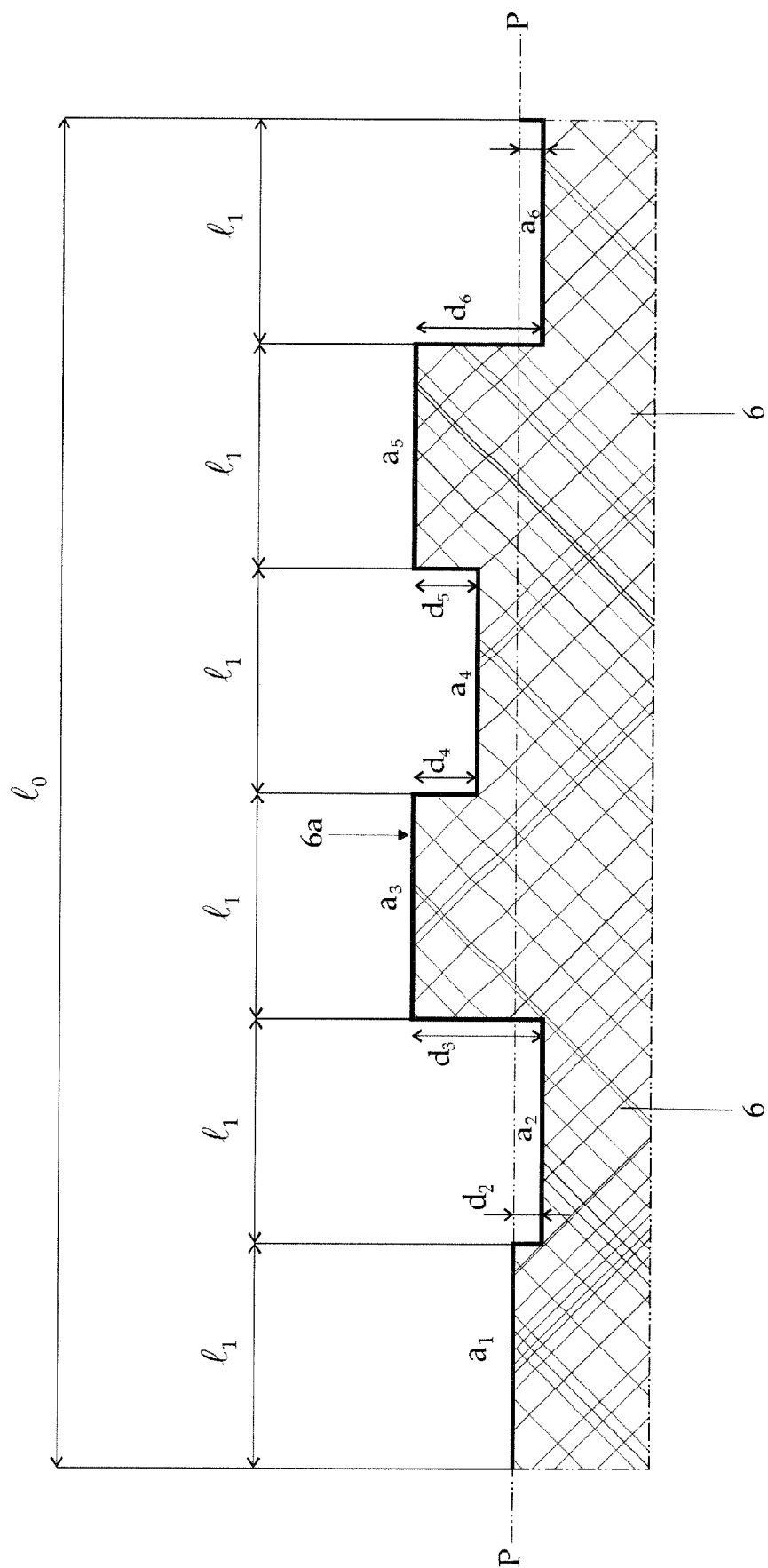


Fig. 4

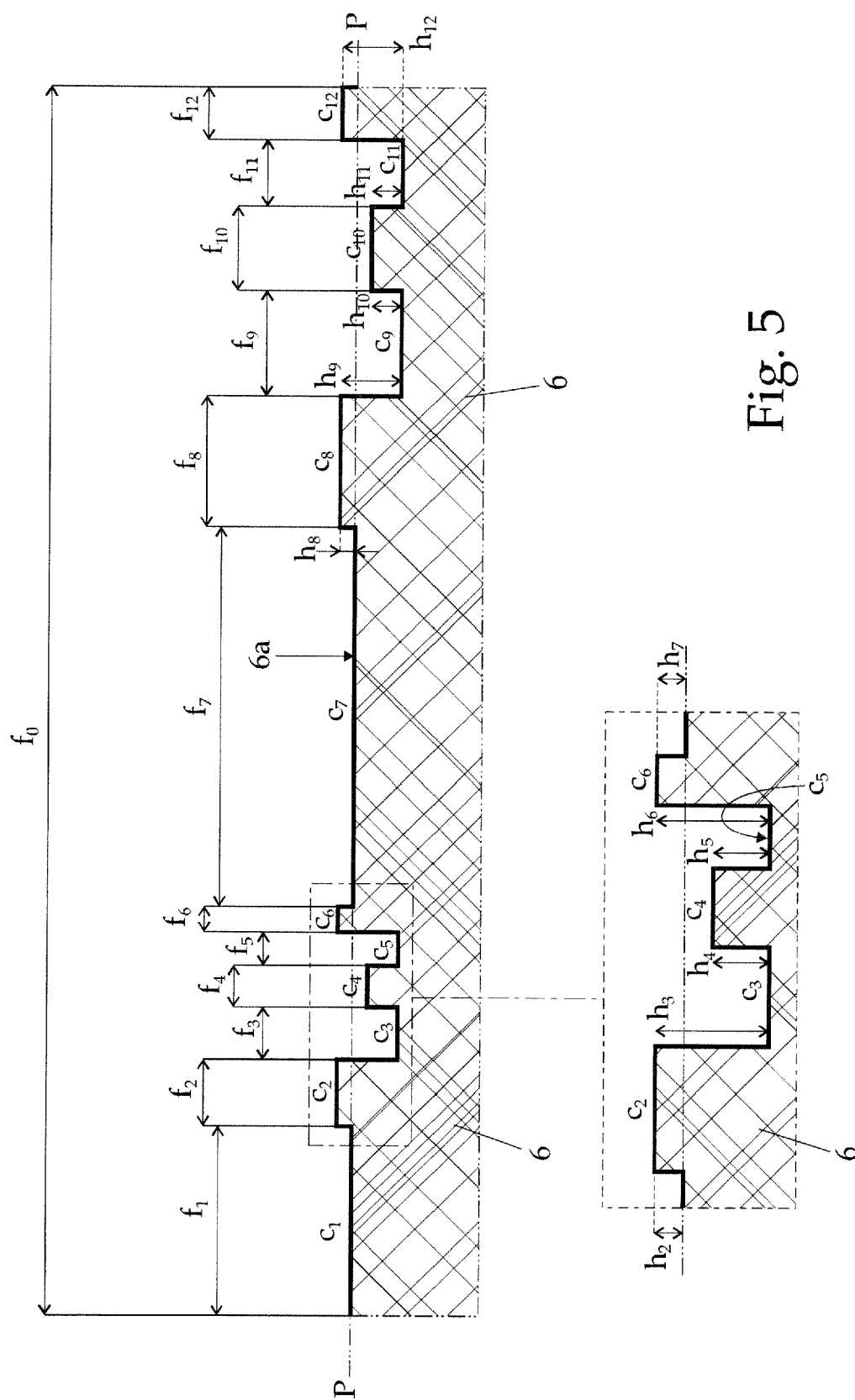


Fig. 5

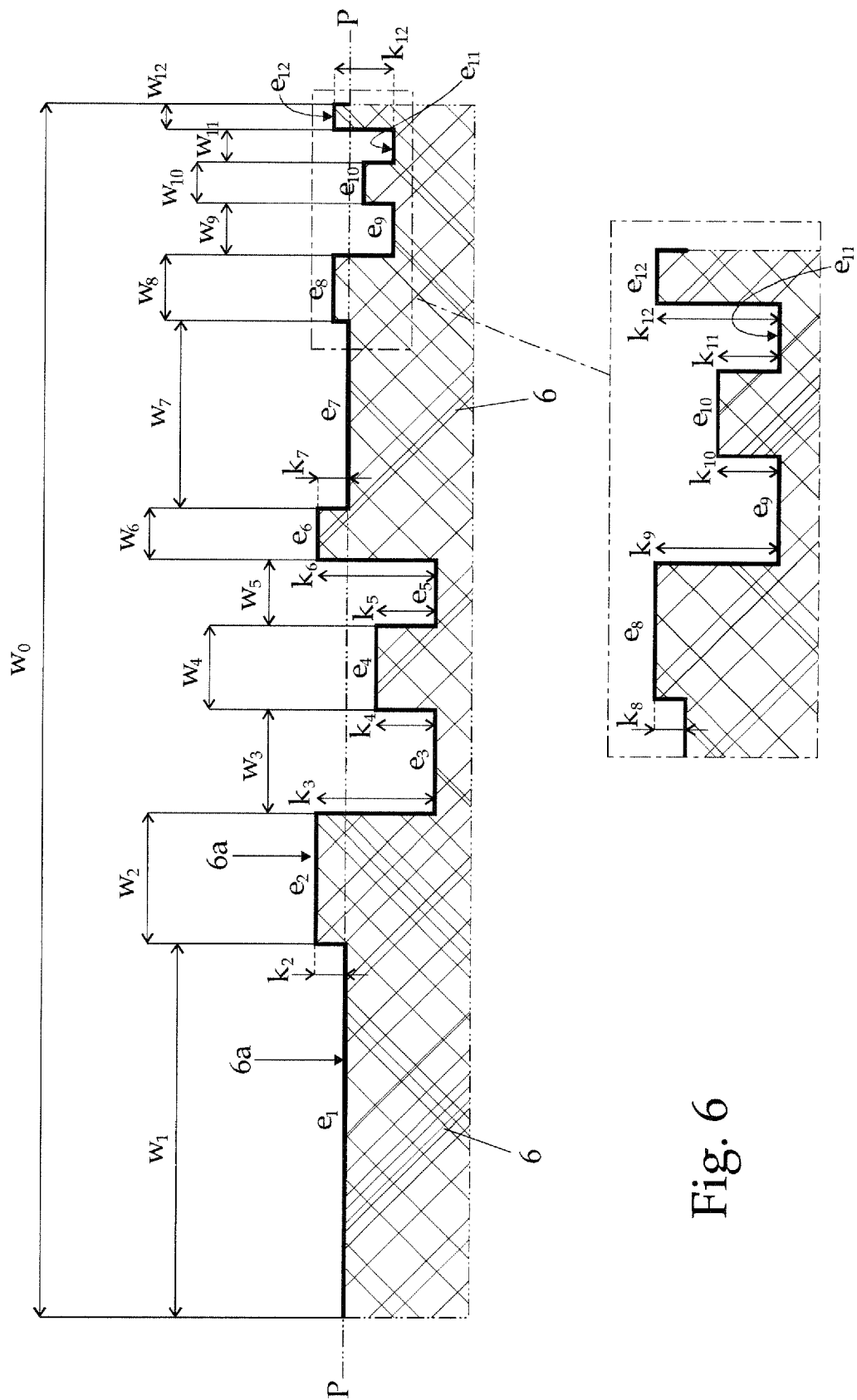


Fig. 6

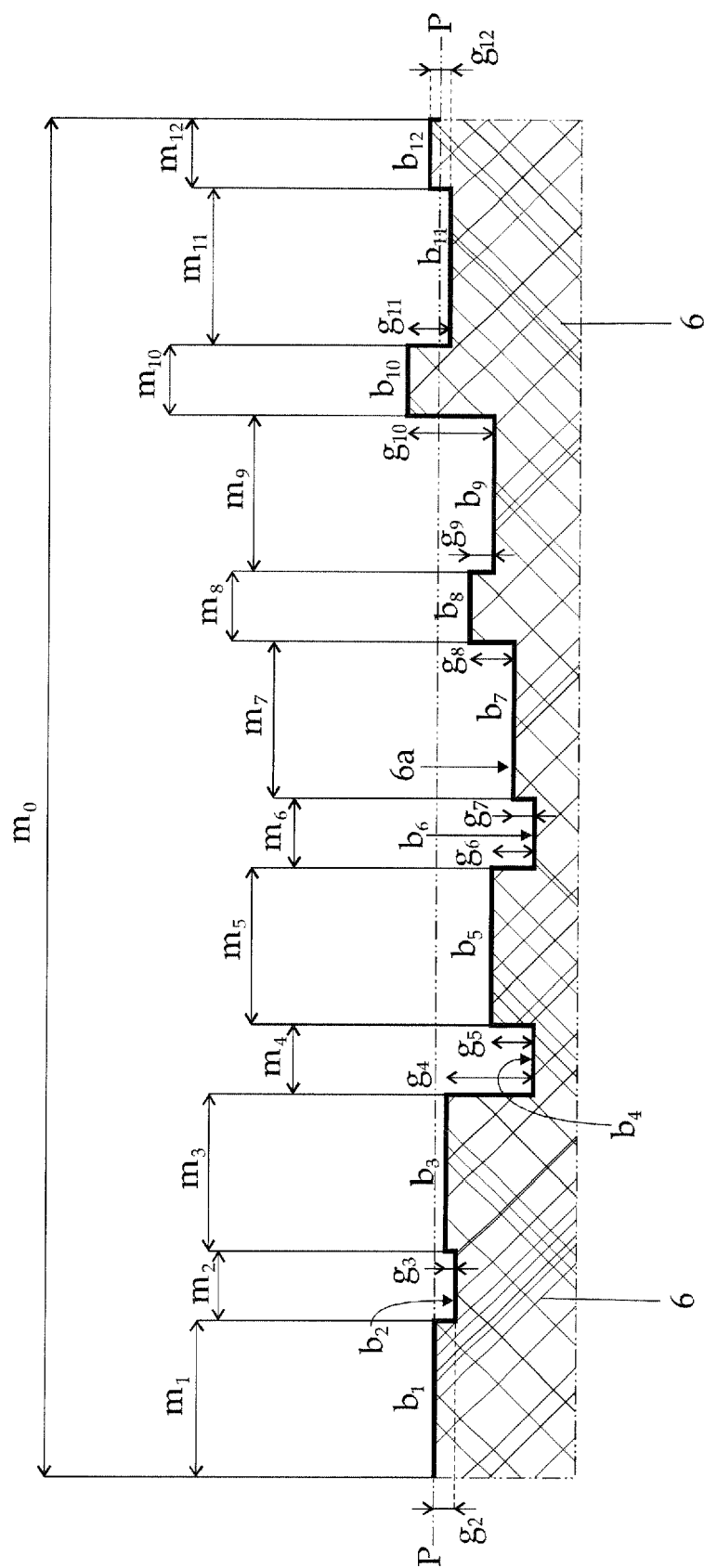


Fig. 7

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Non-patent literature cited in the description

- **M.R. SCHROEDER.** Diffuse Sound Reflection By Maximum-Length Sequence. *Journal of Acoustic Society of America*, 1975, vol. 57, 149-150 **[0102]**
- **Y. ANDO.** Concert Hall Acoustics. Springer, 1985 **[0102]**