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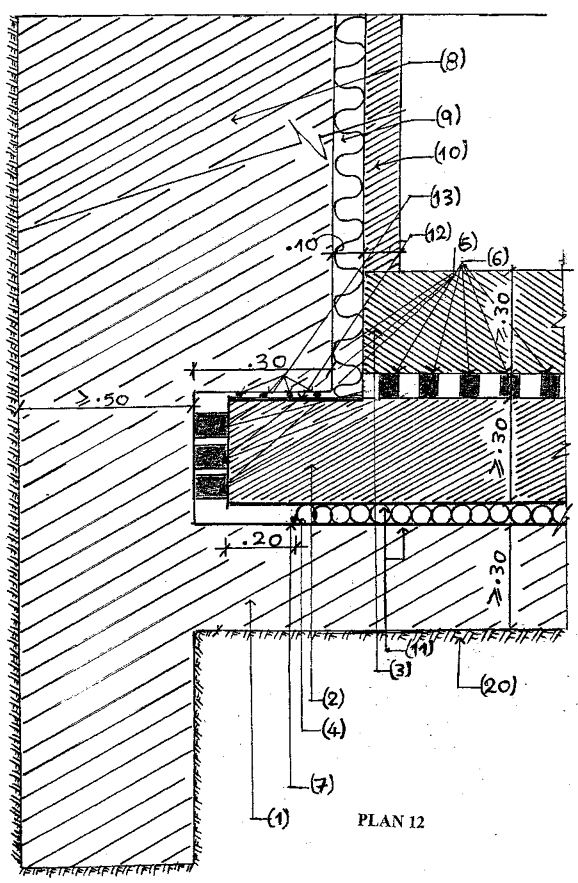
(54) **Aseismic foundation**

(57) The aseismic foundation consists of three plates (1,2,3) of reinforced concrete. Plate (1) touches the ground (20). Between plate (1) and plate (2) there are rigid metal spheres (4), and between plate (2) and plate (3), there are vertical compression-tension springs (6). Plate (2) is connected with horizontal compression-tension springs (5), to a reinforced concrete anchor wall (3), which is fixed to the ground (20) and solid-webbed attached to plate (1). Thus, the anchor wall (8) and plate (1) follow exactly the movement of the ground (20). The horizontal metal springs (5) are positioned symetrical and perimetrical on plate (1), having the same total elastic constant for both its vertical directions. The total elastic constant of spring (5) is such, that the characteristic period of the horizontal movement of the system plate (2), plate (3), springs (5) superstructure (19), is equal with the characteristic period of the horizontal component of the ground vibration. The vertical compression-tension springs (6) have a total elastic constant, which allows for the characteristic period of the vertical movement of the system plate (3), vertical springs (6), superstructure (19), to be double than the characteristic period of the vertical movement of the ground (20).



EP 1 484 450 A2

Description

[0001] This invention is about an aseismic foundation, which fully absorbs the horizontal and vertical component forces of the earth shock. The foundation consists of three plates of reinforced concrete (1, 2, 3). Plate (1) touches the ground (20). Between plate (1) and plate (2) there are rigid . metal spheres (4), and between plate (2) and plate (3) there are vertical compression-tension springs (6). Plate (2) is connected to a reinforced concrete anchor wall (8), which is fixed on the ground (20), by means of compression-tension springs (5), and is solid-webbed connected to plate (1).

[0002] Similar aseismic foundations - which use spheres (4), horizontal (5) and vertical (6) springs - are also mentioned in other inventions.
However, the end result of such constructions is only limited to partial absorbing of the earth sock, and that's due to the difference between the characteristic frequencies of the ground (20) and the springs (5, 6). These are constructed without any prior calculations, and usually are all made the same way, regardless of the characteristics of the ground (20) and superstructure (19).

[0003] The advantage of this invention is that the absorption of both the horizontal and vertical component forces of the shock, is practically 100%, while we exploit the earth shock itself for the springs' strain (5), (6). The specifications of the springs (5) and (6) are calculated by mathematical formulas, based on the characteristics of the specific ground (20) and superstructure (19), such as the characteristic period and the weight respectively.

[0004] The aseismic foundation achieves one hundred percent absorption of the horizontal component force of the earth shock, and at the same time, the absorption of the kinetic energy of the construction, by the developed potential energy of the attached horizontal springs (5), which are strained because of the opposite horizontal component of the ground movement, in relation with the horizontal movement of the plate (2), by means of the metal spheres (4) that are placed in-between.

[0005] It also achieves one hundred percent absorption of the vertical component force of the earth shock, and the absorption of the kinetic energy of the plate (3) - superstructure (19) system, by the developed potential energy of the vertical springs (6), which are strained because of the opposite vertical component of the ground (20) movement, in relation with the vertical movement of plate (3) - superstructure (19). This happens because the characteristic period of the plate (3) - superstructure (19) system, is double than the characteristic period of the vertical component force of the shock.

[0006] The invention is described in the following pages, including mathematical analysis, diagrams and an example

Horizontal component of the earth shock

[0007] Figure 1 shows a diagram of the plate (1), the metal spheres (4), the plate (2), the horizontal spring (5), the anchor wall (8) and the ground (20).

[0008] Supposing that ε is the average percentage on the gravitational constant (g), of the horizontal acceleration component imposed on the constuction [horizontal plate (1) and upwards]. We will examine the movement in time t=T/4, where T is the period of this enforced horizontal vibration component.

[0009] The kinetic energy of the construction will be:

$$W\kappa\iota\nu = \tfrac{1}{2}\,(B/g).v^2 = \tfrac{1}{2}.\,(B/g).\,\varepsilon^2.g^2.t^2 \quad \mathbf{(1)}$$

[B: the weight of the construction, g: the gravitational constant (g = 9,81m/sec^2), v: the velocity at the end of time t]. Also, the strain of spring (5) by X due to the shock, creates potential energy:

$$W\delta=1/2.\ K.X^2 \qquad (2),$$

K being the total elastic constant of spring (5). To achieve balance, the following formula must apply:

$$W\kappa\iota\nu = W\delta,\ \text{that is}\ \tfrac{1}{2}.(B/g).\,\varepsilon^2.g^2.t^2 = \tfrac{1}{2}.K.X^2 \quad \mathbf{(3)}$$

[0010] However, the law d' Alembert applies: Fshock = B.ε, but Fshock = K.X [as a force that strains spring (5)], thus:

$$B.\varepsilon = K.X, \text{ and } X = B.\varepsilon/K \quad (4).$$

According to formula **(4)**, formula **(3)** becomes:

$$(B/g).\varepsilon^{2\cdot}g^2t^2 = K.B^2.\varepsilon^2/K \text{ 'A}\rho\alpha : t = T/4 = V\overline{B/(gK)}, \text{ so } T = 4\ \overline{VB/(gK)} \quad (5).$$

But this period of the vibrating construction will be equal to the characteristic period of the horizontal shock component, which can be determined with test seismic inputs.

[0011] Therefore, with the formula **(5)** which includes the known parameters of the characteristic period of the horizontal shock component and the weight (B) of the construction [base (1) and upwards], we can calculate the required elastic constant K of the horizontal springs (5). We know that the direction of the earth shock is random. We shall prove that the symetrical, perimetric positioning of the horizontal springs (5) gives the same total elastic constant of the springs, for any random horizontal direction.

[0012] Supposing K is the total elastic constant to the direction x-x, and the same K is the total stiffness to the direction y-y. (Please note that per direction, half of springs (5) act as compression springs, and half as tension springs.) According to Figure 8, and because the triangles are approximately right-angled, due to the small angles θ and θ', the formulas for a random horizontal direction (α) seismic motion are:

[0013] Work absorbed by springs (5), by directions y and x:

$$W\psi/ = 1/2.K(\varepsilon\theta)\alpha^2\cos^2\varphi + 1/2.Kc.\alpha^2\sin^2\varphi \quad (6)$$

$$Wx = 1/2.K(\varepsilon\theta)\alpha^2\cos^2\varphi' + 1/2.Kc.\alpha^2\sin^2\varphi' \quad (7)$$

Thus:

$$W\text{total} = W\psi + W\chi = ½.K(\varepsilon\theta).\alpha^2(\cos^2\varphi + \sin^2\varphi) + 1/2.Kc.\alpha^2(\cos^2\varphi' + \sin^2\varphi') = 1/2\ \alpha^2(K\varepsilon\theta + Kc) \quad (8)$$

($K\varepsilon\theta$ = the elastic constant for compression - tension, and Kc the elastic constant in non-loaded conditions.
Relation (8) is proved by Figure 3, as follows:

$$B'\ A'\ X' = \varphi' + \theta' = BAX \quad (9),$$

$$BAX + \theta = \Pi/2 - \varphi,\ BAX = \Pi/2 - \varphi - \theta \quad (10).$$

Formulas **(9)** and **(10)** give:
$\varphi' + \theta' = \Pi/2 - \varphi - \theta$, $\varphi' + \varphi = \Pi/2 - (\theta + \theta') = \Pi/2$, because $\theta = \theta' = 0$
(approximately)

[0014] But because of the different characteristics of the ground (20), the characteristic period of the earth shock is also different for each direction. Therefore we suggest:

1. To calculate the characteristic periods of the shock, for various directions in a radial configuration, and to use the average of these periods as the characteristic shock period of the ground (20).

2. To build an underground construction like the one shown in Figures 4 and 5 (plan and cross section respectively), which because of its shape I call "reversed glass".
This construction will consist of a closed-cylinder wall (17), its plate (16) and its shoe (18). In any earth shock, this construction will move with the same characteristic period at all horizontal directions, due to the relatively big difference in the stiffness between the shoe (18) and the wall (17), and due to the symmetry. This characteristic period will also be the characteristic period of the vibration of the ground, for the aseismic foundation above.

Vertical component of the earth shock

[0015] Figure 10 shows a diagram of plate (3), the superstructure (19), plate (2), and the vertical compression-tension springs (6). If $T_{\kappa,\varepsilon}$ is the characteristic period of the vertical shock component and $T_{k,c}$ the characteristic period of the vertical movement of the system vertical springs (6) / plate (3) / superstructure (19), which is calculated by formula **(5)**, then, in order to achieve full absorption of the kinetic energy that will be developed in the system plate (3) / superstructure (19) [from the vertical movement of the ground (20) in the +z direction], by the respective potential energy of the spring (6) (strained in the direction -z), this formula must apply: $\mathbf{T_{\kappa,c} = 2\, T_{\kappa,\varepsilon}}$.
Therefore, with the known parameters of the characteristic period of the vertical shock component and of $T_{\kappa,\varepsilon}$, and for $\mathbf{T_{\kappa,c} = 2\, T_{\kappa,\varepsilon}}$, we can calculate the required elastic constant of the vertical metal compression-tension springs (6), using formula **(5)**.
For the final selection of the vertical springs (6), we must make sure that after the imposing of the total static charge, the remaining uncompressed travel of the vertical springs (6) is at least equal to the expected maximum width of the vertical component of the earth shock. The following formula applies:

$$zmax = \frac{T_{\kappa,\varepsilon}^{\;2}}{16}\,.\,g \qquad (11),$$

where $T_{\kappa,\varepsilon}$ is the characteristic period of the vertical shock component and g is the gravitational constant (g = 9,81m/sec^2).
[0016] Formula (11) is proved as follows:
For any given ground mass that moves, and being connected to the adjacent masses, produces in relation to them a stiffness K. Formula **(5)** gives:

$$Tk,e = 4\sqrt{B\,/\,g(k)}\ .$$

Thus: $\mathbf{T_{\kappa,\varepsilon}^2 = 16\ B/(g)\ (k)}$. However, the principle D'Alembert and the elastic strain equation (**B.**ε = **K.z)** also apply, therefore **B/K = zmax** (when ε=1).
The combination of the above equations gives us:

$$zmax = (T_{\kappa,\varepsilon}^{\;2}/16).\ G\ (11).$$

(Note: for ε<1 we have $\mathbf{Z = (T_{\kappa,\varepsilon}^2/16).\ g.\varepsilon}$, where $T_{\kappa,\varepsilon}$ is the characteristic period of the vertical shock component, **B** is the weight of the ground mass, ε is the percentage of the imposed acceleration on the gravitational constant, and g is the gravitational constant (g = 9,81m/sec^2).
[0017] The positioning of the vertical springs (6) under the bearing elements (supports) (22), is made in accordance to the load of each support, so that we have the same uncompressed travel. The springs are positioned within a frame of dimensions $1_x + 2d$, $1_y + 2d$, where 1_x, 1_y are the dimensions of the shoe (23).
[0018] Figure 7 shows an easy way of placing the spheres (4), which are enclosed in an elastic membrane frame (7) the height of which is 2 cm, and its dimensions (D-40)cm x (D-40)cm. The 20cm margin is necessary for the rolling of the sphere.
Figure 8 shows the form of the springs (5) and (6). They include two plates (22), one on each side, the anchoring lengths (14) and the anchoring reinforcements Φ12 (15). For easier positioning at the construction site, it is best to prefabricate the springs in groups, using Montage reinforcements.
[0019] Figure 9 shows the distribution of the supports on two bases, in cases of multi-floored or extended plan buildings.
Figure 12 shows in detail the aseismic foundation in half-section. It includes plate (2), the metal spheres (4), the lower plate (1), which is placed on the ground (20) and is connected solid-webbed to the anchor wall (8). Plate (2) is connected to the anchor wall (8) through the horizontal springs (5), incorporated and founded to the ground (20). There is also the elastic sealer of the seam (9) and the wall (10), which isolates the entire foundation from the main construction. Finally, there is the membrane that encloses the spheres (4).
Attached on the upper side of plate (1) and on the lower side of plate (2) are cast iron plates (11), 30mm thick. Also, to avoid the loss of contact between the spheres (4) and plates (1) and (2), due to the vertical component of the shock, plate (2) is connected to the anchor wall (8) with a contact plate (12), 5mm thick, attached to plate (2), and contact reinforcements Φ8 (13) on the anchor wall.

Also shown are the vertical springs (6), anchored on the upper side of plate (2), and on the lower side of plate (3). The upper side of plate (3) is the foundation level of the superstructure (19).

[0020] For the materials, we suggest:

1. Spheres (4): steel, 10mm - 40mm diameter.
2. Plates (1), (2) and (3): reinforced concrete.
3. Springs (5), (6): Stainless, with any of the known methods.
4. Elastic seam sealer (9): It must have a small elastic constant, so that it does not affect the function of the mechanism.

The testing of springs (5) must be done with open maximum tension of the longitudinal and flexural strain. The calculation of the anchor wall (8) and springs (5) is made with the "short cantilever" method.

EXAMPLE

[0021] Assuming we have a five-storey apartment building, with a typical floor plan of $10m \times 10m^2$ (=100 m^2). The pre-calculated total weight [plate (2) and above] is B1 = 850tn, and the net weight [w/o plate (2)] is B2 = 780tn. The test seismic input gave ground T for the horizontal component of the shock = 0.17sec, and ground T for the vertical component of the shock = 0.15sec. We will calculate the "Aseismic foundation".

[0022] CALCULATION OF THE SPHERES (4)

(for the selected spheres: Φ40 mm)

[0023] Number of spheres :

$$\eta = \frac{(1000\text{-}40)}{4} \text{ X } \frac{(1000\text{-}40)}{4} = 57.600$$

[0024] Average load on each sphere: 850.000/57.600 = 14.75Kρ (allowed).

[0025] CALCULATION OF HORIZONTAL SPRINGS (5):

Formula (5) gives:

$T = 4\sqrt{B/(gK)} = 0{,}17$, thus: $4\sqrt{850(981K)} = 0{,}17$, gives K = 480,22 t/cm (required).

Formula F=K.x = B.ε, with ε=1 (100%g), gives χ = 850/480.22 = 1.77cm, which is the lower limit of the required travel fn for springs (5).

After a number tests, including the open total tension, the selected spring will have the following characteristics:

d==14mm, Ln=9,54cm
Dm=80mm L=13,17cm
i=5,5 Fn=807,31Kp
fn=3,63cm

[0026] From the calculation of the springs (5) we get:

$K_{total} = K_{longitudinal} + K_{flexural} = 22{,}24 + 18{,}73 = 40{,}97$ Kp/mm
K_{total} = the total elastic constant of springs (5)
$K_{longitudinal}$ = the elastic constant of springs (5) for compression-tension $K_{flexural}$ = the elastic constant of springs (5) for flexion.
Total open tension:
Tmax = $1{,}868\chi + 2{,}627\chi = 4{,}49 \text{ X } 1{,}77 = 79{,}4\text{Kp/mm}^2$ (allowed).

[0027] Therefore, the number of springs (5) is calculated as follows:

λ=480,22 / 0,4097 =1.172 springs in each direction (x-x), (y-y).

That is, λ=586 springs (5) in each side of plate (2), which will be positioned in six rows, each having ten springs per meter.

[0028] The edges of the plate are shaped in a way that will allow the "reception-anchoring" of springs (5) (Figure 13).

[0029] CALCULATION OF VERTICAL SPRINGS (6):

We must have:

$T_{k,c} = 2\ T_{\kappa,\varepsilon}$
$4\ \sqrt{B2/(g).(k)} = 2X0{,}15 = 0{,}30 = 4\ \sqrt{780/981.K}$
K (required) = 141,35 tn/cm. (required total ελκυστι κή (elastic?) constant) Formula (11) for $T_{\kappa,\varepsilon}$ = 0,15sec gives:

$$Ymax = \frac{(0{,}15)^2}{16} 981 = 1{,}38cm,$$

which is the maximum expected width of the vertical shock component for ε = 1 (100%.g).

[0030] The selected spring (6) will have the following characteristics:

d=16mm, Dm=125mm, Fn=756Kp, ln=98mm, fn=75mm, i= 5.5
K spring = 100,8Kp/cm.

Therefore, the number of springs (6) is calculated as follows:

λ= 141,35/0,1008 = 1402 springs (6).
The weight imposed on each spring (6) is: Bλ=780.000/1402 = 556,3Kp.

The remaining uncompressed travel after the loads will be:

f'n = 7,5 - 556,3/100,8 = 1,98cm>1,38cm.

[0031] POSITIONING OF VERTICAL SPRINGS (6):
Springs (6) are positioned under each support (22), in a frame with the following dimensions:
Ix + 0,30, Iy + 0,30 [Ix and Iy are the dimensions of the shoe (23)].
The number λi of springs is:
λi = Pi (Kp) / 100,8 (kp/cm) X 5,5cm (Pi is the load of the support (22) in Kp, 100,8 is the elastic constant of each spring (6) in Kp/cm, and 5,5cm is the travel of springs (6) in cm).
The entire base is shown in Figure 13.
[0032] Besides the protection of the superstructure (19) against earthquakes, the aseismic foundation, ensures perfect moisture insulation, due to the required seams and the metal spheres (4).
Also, besides large-scale constructions (buildings, bridges, water towers, silos etc.), the aseismic foundation can be used for the protection of various fragile objects, instruments etc. In such cases, we use the characteristic period of the building where the foundation will be placed [with formula (**5**)], taking also under consideration the respective absorption factor.

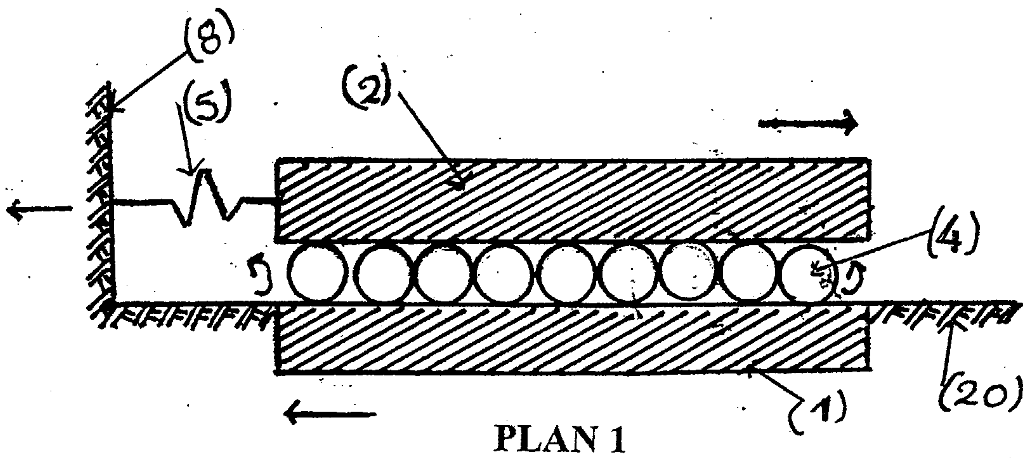
Claims

1. The aseismic foundation consists of three plates (1, 2 and 3) of reinforced concrete. Plate (1) touches the ground (20). Between plate (1) and plate (2) there are rigid metal spheres (4), and between plate (2) and plate (3), there are vertical compression-tension springs (6). Plate (1) is connected with horizontal compression-tension springs (5), to a reinforced concrete anchor wall (3), which is fixed to the ground (20) and solid-webbed attached to plate (1). Thus, the anchor wall (8) and plate (1) follow exactly the movement of the ground (20). The horizontal metal springs (5) are positioned symetrical and perimetrical on plate (1), having the same total elastic constant for both its vertical directions. The total elastic constant of springs (5) is such, that the characteristic period of the horizontal movement of the system plate (2) / plate (3) / springs (5) / superstructure (19), is equal with the characteristic period of the horizontal component of the ground vibration. The vertical compression-tension springs (6) have a total elastic constant, which allows for the characteristic period of the vertical movement of the system plate (3) / vertical springs (6) / superstructure (19), to be double than the characteristic period of the vertical movement of the ground (20).

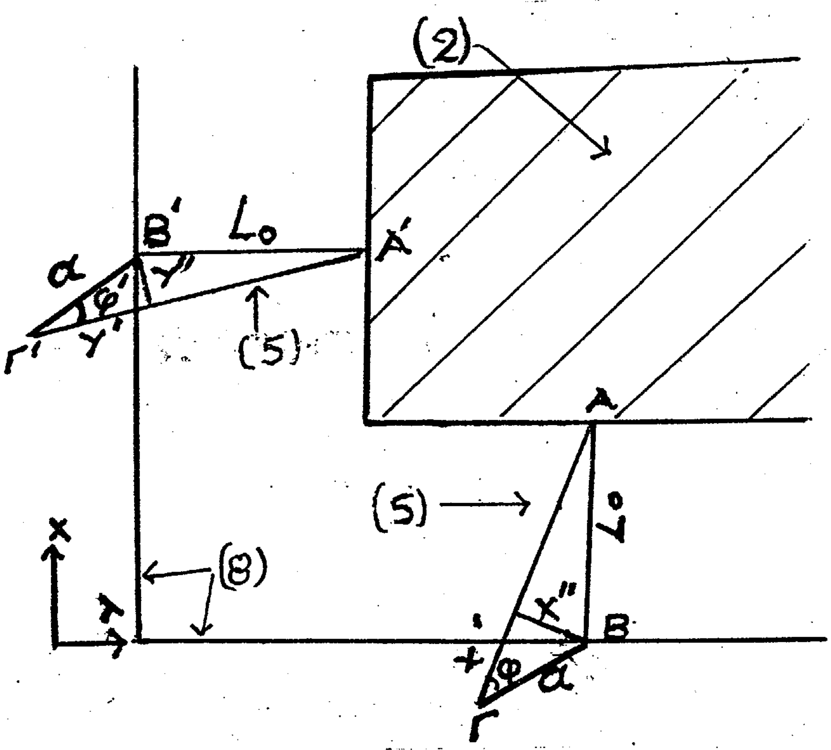
2. Aseismic foundation, according to requirement 1, that is based on an underground construction that I call "reversed glass", which consists of a reinforced concrete closed-cylinder wall (17), covered with a reinforced concrete plate (16), and has a reinforced concrete shoe (18). This construction has the same characteristic period of movement

to all horizontal directions, due to its symmetry.

3. Aseismic foundation according to requirement 1, which has received symmetrical, concentric groutings (21) underneath plate (1), in efficient depth. The groutings homogenize the ground, giving to it approximately the same characteristic period with the horizontal component of the earth shock, to all horizontal directions.



PLAN 1



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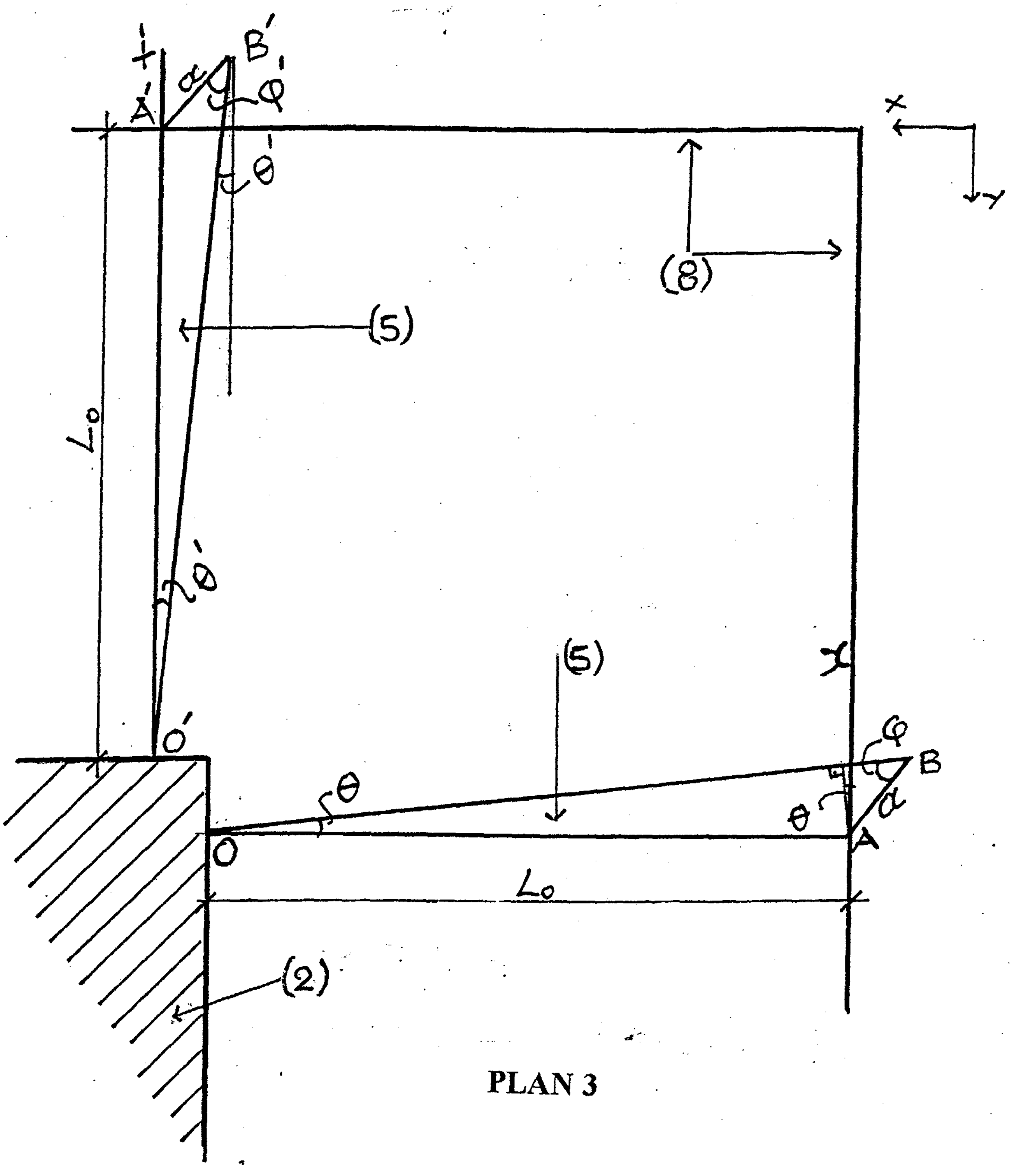

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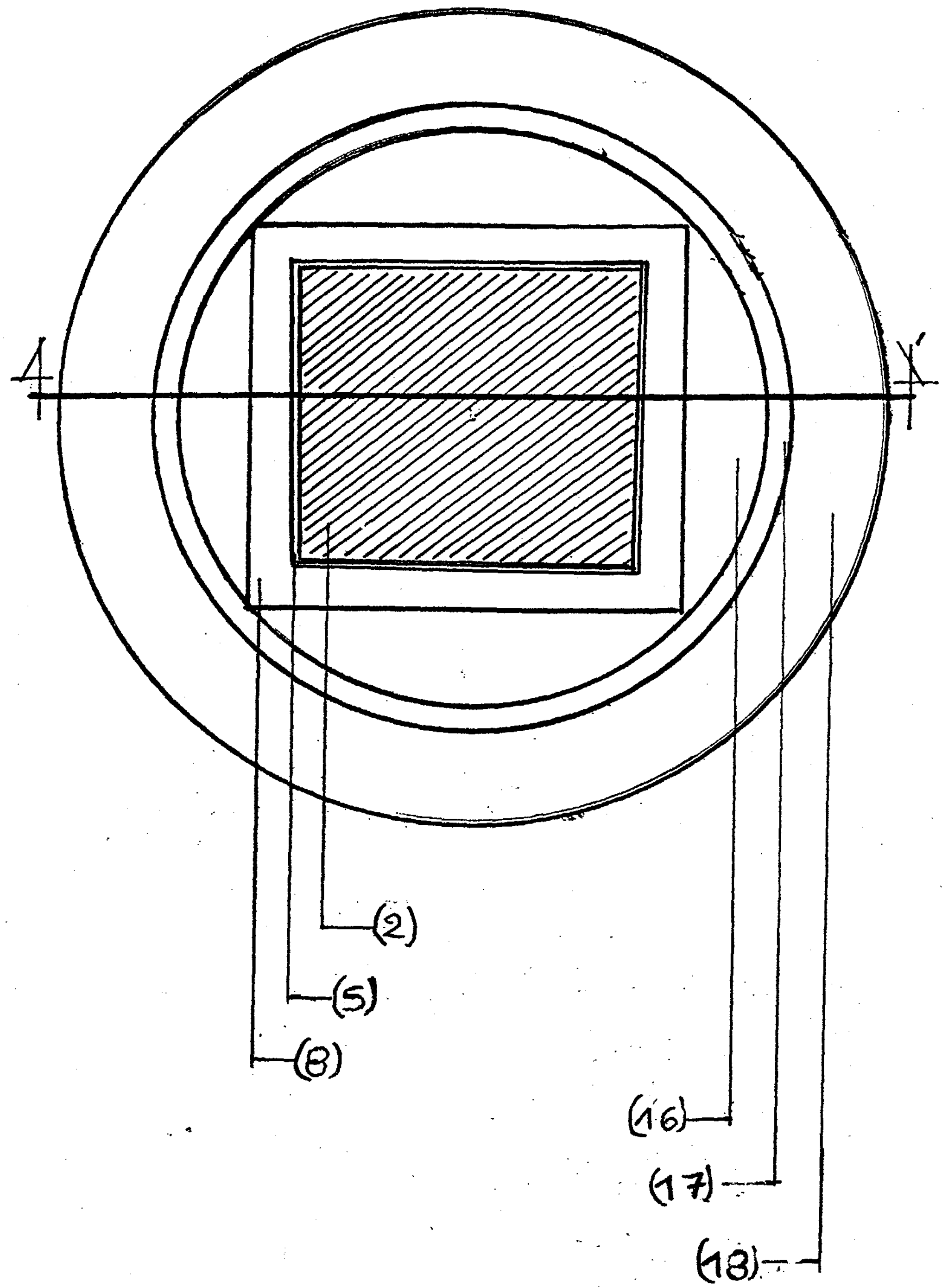

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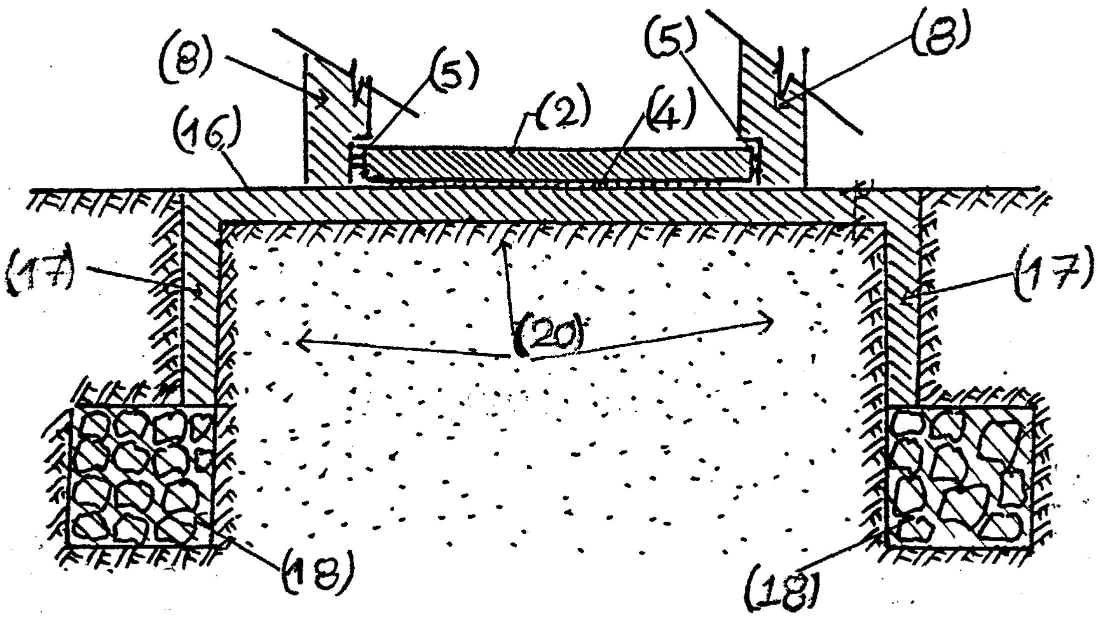

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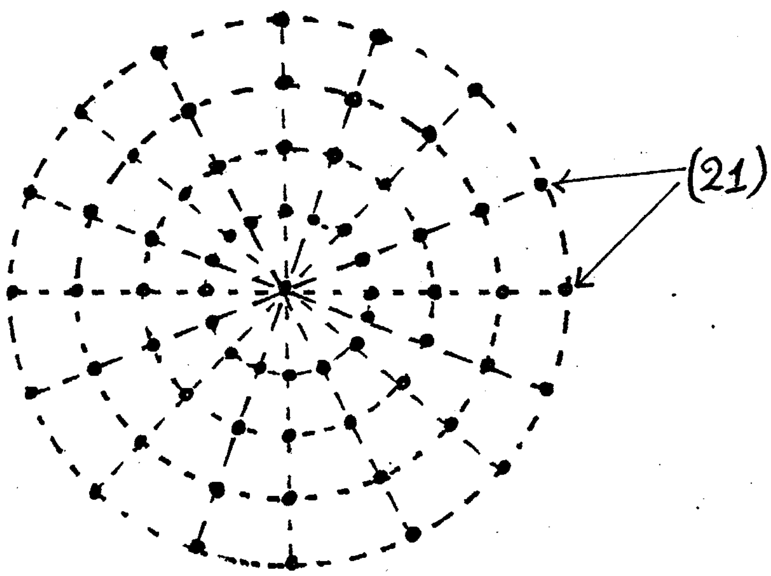

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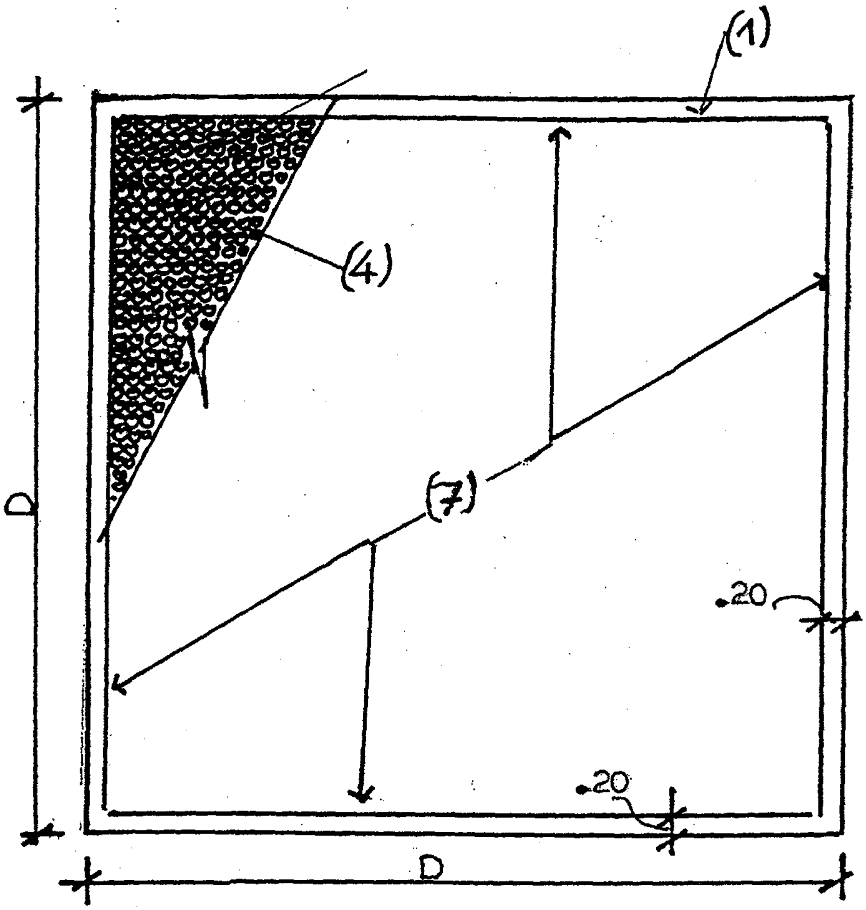

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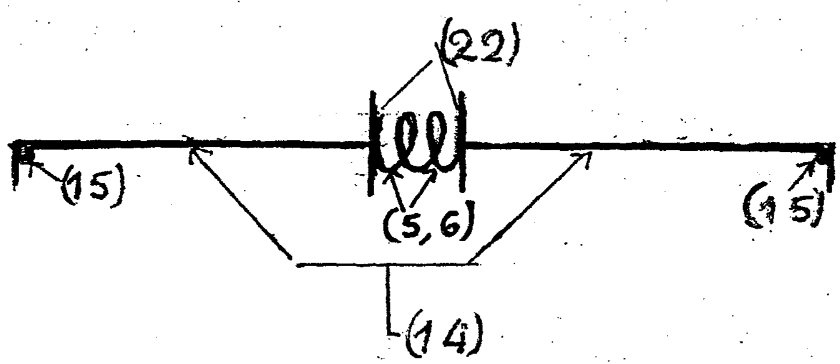

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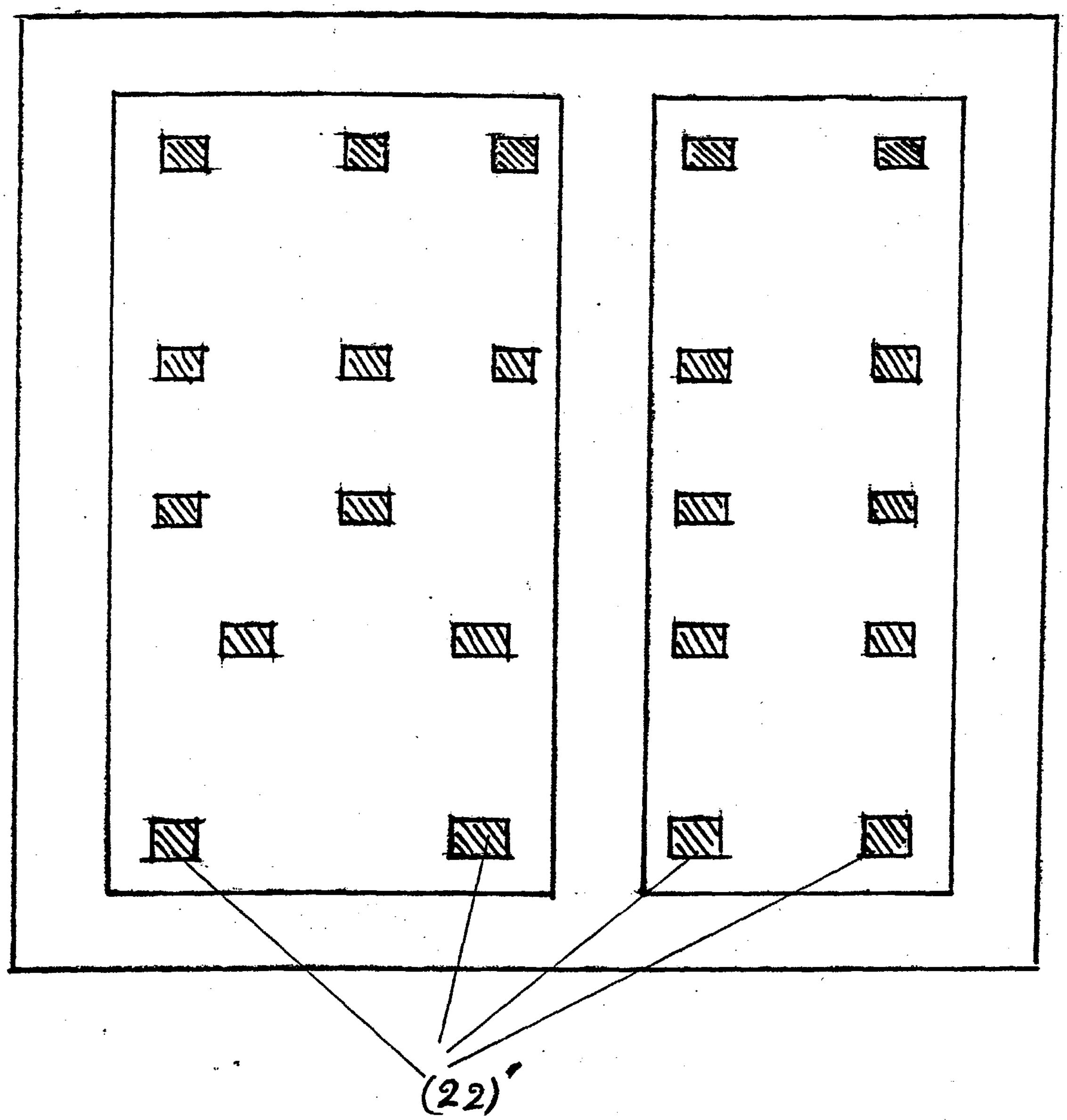

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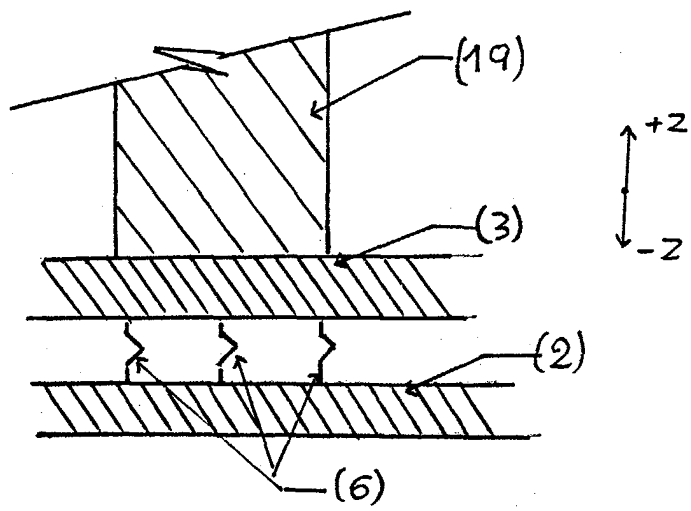

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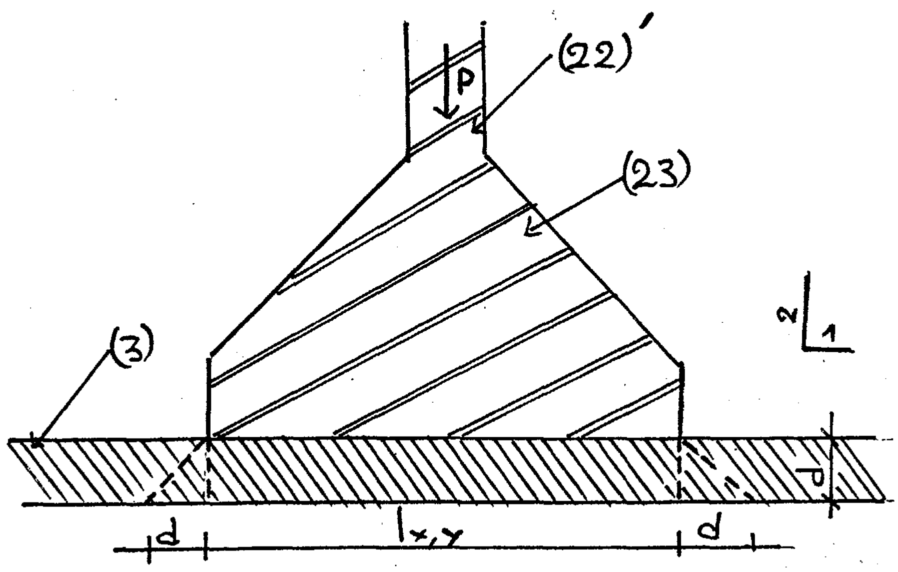

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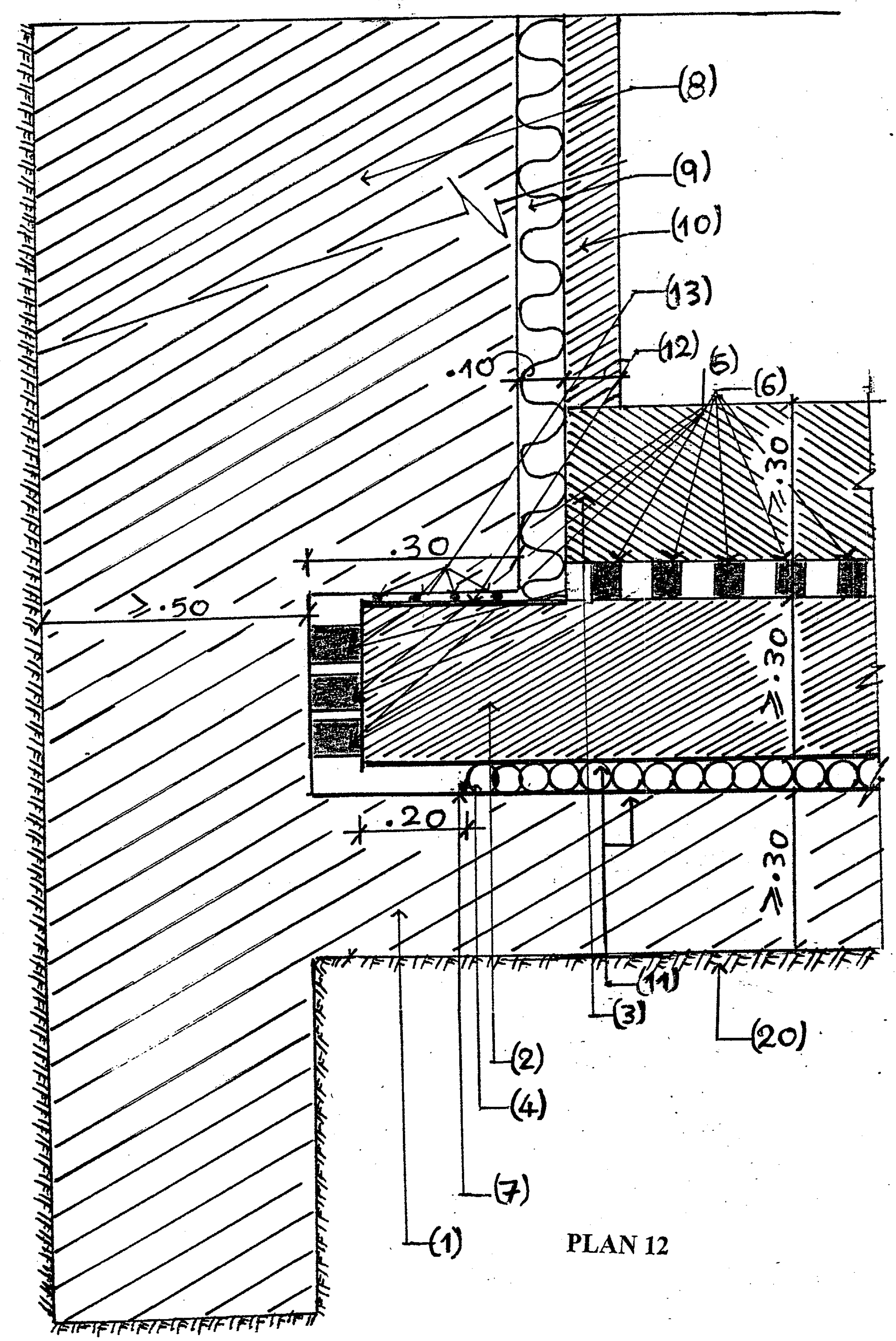

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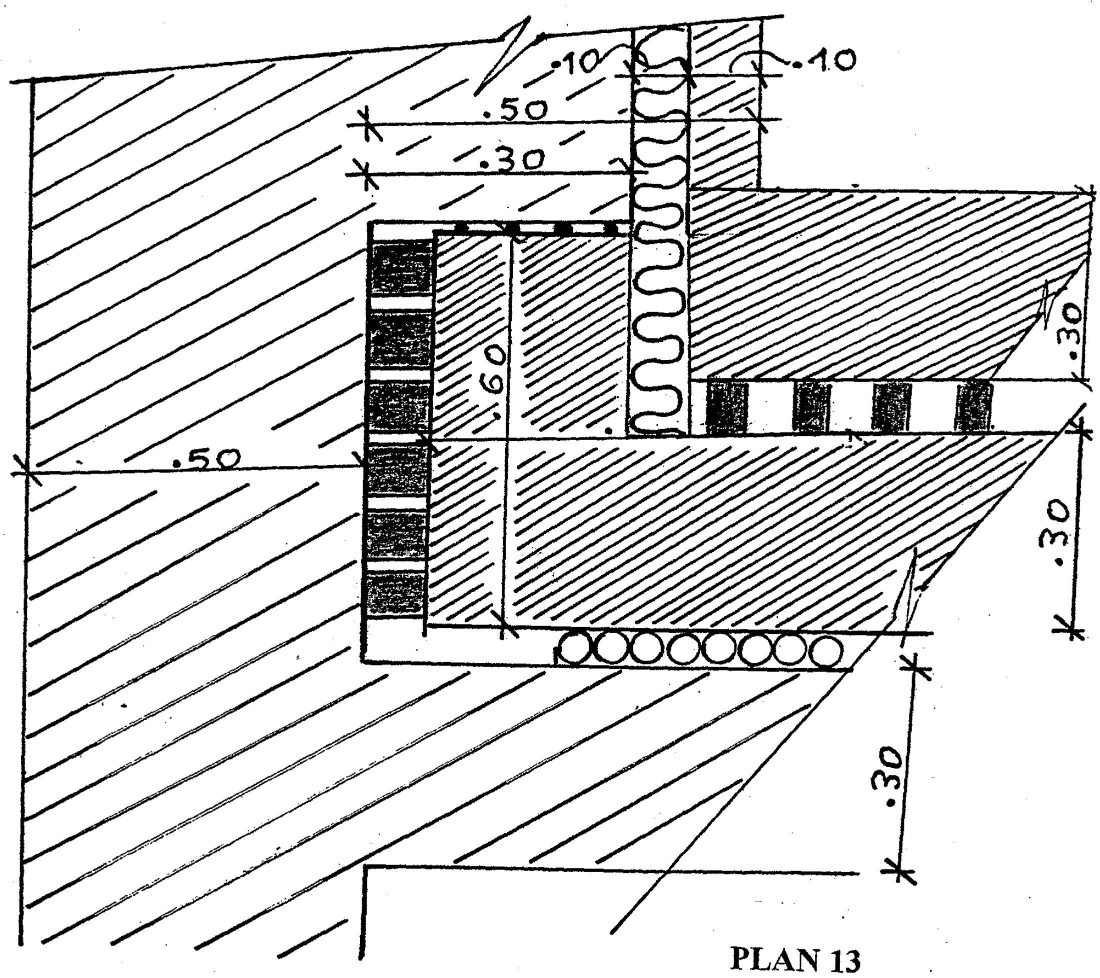

PLAN 13