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A Way to Increase the Resistance of Supporting Structures that are Already Built Against Seismic Forces

by

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SUMMARY

The object of this paper is to describe the methods used in Greece by the Hellenic Institute for the Application of Science in order to increase the resistance of structures that are already built,against seismic forces.The technique proposed and used by the Hellenic Institute is thoroughly described and illustrated by Fig.2,8,II,I2 and I3.

RESUME

Le but de ce papier est de décrire les méthodes pratiquées en Grèce par l'Institut Hellénique pour l'Application de la Science pour augmenter la résistance que les constructions déjà bâties peuvent présenter aux effets sismiques.Ces techniques sont illustrées par les Figures 2,8,II,I2 et I3.

ZUSAMMENFASSUNG

Der Zweck dieser Veroffentlichung ist zu geben eine Beschreibung der Verfahren des Griechischen Instituts für die Anwendung der Wissenschaften,die in Griechenland für die Verstärkung alten Gebäude gegen Erdbeben benützt sind.Der Verfasser beschreibt ausführlich die Technik zur Verstärkung,die im Abbild 2,8,II,I2 und I3 dargestellt ist.

II. 34

THE THINGS THAT WE MUST DO IN ORDER TO STRENGTHEN OLD STRUCTURES AGAINST SEISMIC EFFECTS

1) We make the structures lighter in weight and the heavy masses untouchable by seismic effects.
The first thing to do is to make the structure lighter in weight.Therefore all heavy masses that can be transported in order to be brought to rest directly upon the ground in the ground-floor,should be transported there.
Examples: 1) the bulky archives of big companies and public Services must be transported to rest directly upon the ground ; 2) all useless massive objects accumulated in garrets of old houses must be removed from there; people might heap them safely in the basement; 3) heavy stone plates covering roofs of houses built with light walls and light floors,must be replaced by light clay-tiles.
The next thing to do is to free the horizontal motion of the supporting structure of the building from any opposition by heavy masses connected with it.This point is of particular importance,because we do not suggest any removal of heavy masses from the actual position they occupy now in the building; but we suggest to let these masses stay where they are and make them untouchable by seismic effects.
This is done in the following way:
.- The heavy mass does no more rest directly upon the supporting slab that is rigidly connected with the supporting structure as shown in fig.I but it is brought to rest upon a plate that rests upon the antiseismic filter; the antiseismic filter rests upon the supporting slab that is rigidly connected with the supporting structure as shown in Fig. 2. In this way the opposition presented by the heavy mass to the motion of the supporting slab is as small as we wish it to be.For simplicity's sake let us say that it presents no opposition at all to the motion of the supporting slab.This means that the supporting slab is free to move beneath this heavy mass; the heavy mass does neither oppose nor follow this motion;it remains motionless.Therefore,the inertia of this mass is not waked up; so, it exerts no seismic force upon the supporting slab,no seismic force upon the supporting structure.

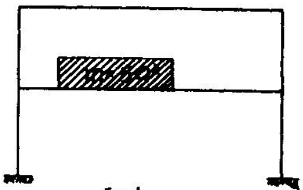


Fig.1

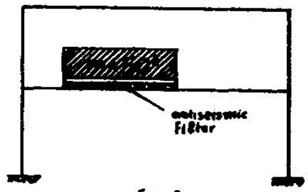


Fig. 2

Numerical application:We suppose that the weight of the supporting structure is 150 t, the weight of the heavy mass is 50 t ,and the acceleration of the ground is e = 0,06.g. Then the total seismic thrust resisted by the columns of the ground-floor in the structure shown in Fig.II is H_I = 0,06x(100+50) = 9t ; the total seismic thrust resisted by the columns of the ground floor in the structure shown in Fig. 2 is H = 0,06x(100) = 6 t.
When the supporting structure is elastically deformable to a sufficiently large extend as is normally true for the upper floors of multistory buildings supported by reinforced-concrete,prestressed-concrete or steel framed structures,then the motion of the slab that supports the heavy mass under consideration is not very rapid.Therefore,elastic bodies keep their elastic properties in front of the corresponding seismic effects. For that reason,in that case we might use "NEOPRENE" or any other adequate "elastomer" instead of the antiseismic filter.So: we introduce an adequate layer of elastomer between the supporting slab and the plate, and bring the heavy mass to rest upon this plate.We calculate the horizontal shearing force induced in this layer by the corresponding stretching,which is equal to the expected amplitude of the seismic motion of the supporting slab.

When it is too difficult to estimate this amplitude, we make the following calculation: A force H acting over the elastomer-layer produces the deformation (s) ; it is $H/K = s$; whence we obtain $K = H/s$; then we write the equation $\ddot{w}.m - K.(x-w) = 0$. For the motion of the ground we admit the equation: $\ddot{x} = e$. We also admit that the supporting slab follows exactly the motion of the ground; then it is: $x = e.t^2/2$ and the differential equation for the motion of the mass becomes:

$$\ddot{w}.m + w.K - \frac{e.K}{2}.t^2 = 0$$ which is governed by the limit conditions:

for $t = 0$: $w = w' = \ddot{w} = 0$; and it is true in the very small interval $0 \rightarrow t$.
For an approximate solution we use the expression: $w = f.t^3 + j.t^4$ because it satisfies the limit conditions. Then we have: $\ddot{w} = 6.f.t + 12.j.t^2$ and we obtain $w \cong 3.e.K.t^4/24.m$ and $H = K.w = 3eK^2t^4/24m$.
Of course, we have to select the largest value of t ; this is an estimation. Then we have the value of the seismic thrust produced by the mass m. This is the seismic force with which the mass m will act upon the supporting structure.

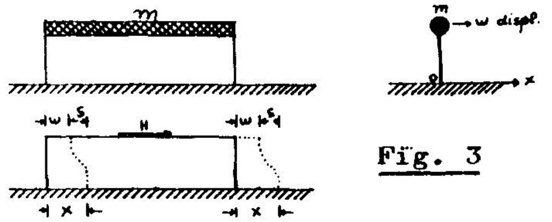


Fig. 3

The use of the antiseismic filter or of elastomer-layers in order to isolate heavy masses from the supporting slabs and make them largely untouchable by seismic efffects, is a very simple and absolutely efficient technique. People living in seismic zones or working in the building business in seismic zones, should be familiar with this technique.
It seems to me that the following suggestion might help these people in their arguments:
Let us consider the house shown in Fig. 4. The weight of the supporting structure (i.e. of the reinforced-concrete frame) is $W = 50t$; a heavy mass resting directly upon the supporting slab weigths 20t. Therefore the total seismic thrust acting upon the columns of the ground floor is

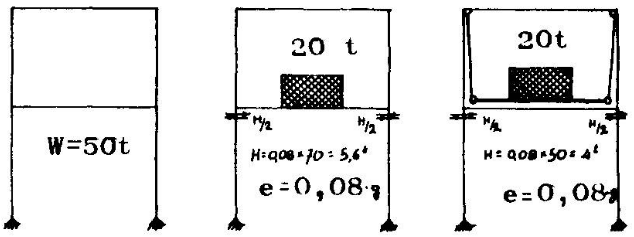


Fig. 4

$H = 0{,}08X(50+20) = 5{,}6$ t. Let us hang the heavy mass from the ceiling of the room; now this weight moves freely as a pendulum and offers absolutely no opposition to any seismic motion of the supporting structure. Therefore: seismic motion will not affect the motion of the heavy mass m in any significant way. This means that as far as seismic effects upon the supporting structure are involved, this heavy mass practically does not exist ! The total seismic thrust acting upon the columns of the ground floor is not $H = 5{,}6$ t ; but it is only $H = 50x0{,}08 = 4$ t.
Similarly let us consider the high building shown in Fig. 5. The weight of the supporting structure is $W = 1000$ t; the weight of live loads on it is $W = 1000$ t; when these live loads rest directly upon the supporting slabs, the total seismic thrust upon the columns of the ground floor is $H = 0{,}06x(1000+1000) = 120$ t. But let us construct a new auxiliary floor for every room and hang it from the ceiling of the room. The new floor moves freely like a pendulum and does not oppose any seismic motion of the supporting structure. All live loads rest upon the new suspended floors. They are practically untouchable by seismic effects. Therefore, the total seismic thrust upon all the columns of the ground floor is now:
$H = 0{,}06x1000 = 60$ t.
Of course, we do not have to construct hanging floors! This was a suggestion made just for arguments' sake. It is much more convenient and economical to use the antiseismic filter or elastomer-layers and bring the heavy masses to rest upon them. The result is very much the same.

The technique of using the antiseismic filter or elastomer-layers as described above, is of course very simple; everybody can use it.
The antiseismic filter can be used equally well to isolate the whole supporting structure from the supporting ground. This work, however, is a very expensive and delicate operation that requires specialists; it should be confined to be used only for special buildings and monumental works of great historical or archeological value. The operation is similar to the procedure of underpinning a whole construction in order to replace the old foundation by a new foundation.
The new foundation includes the antiseismic filter. The operation is considerably more expensive and delicate than a usual renewal of foundations, because we must also connect one with the other all isolated footings.
The new foundation should be constructed exactly as described in my papers presented in Constanta and New York, or else left aside. Arbitrary simplifications and modifications to suit the contractors might result in a deterioration of the situation concerning the building under consideration. This is a case of "All or Nothing".
Therefore we should use the antiseismic filter properly or not use it at all. Of course the same is equally true for any substitute for the antiseismic filter: All or Nothing!
So, I feel that I must repeat it: the use of the antiseismic filter (or of elastomer-layers in upper floors) in order to bring heavy masses to rest upon them, is a very simple technique for everybody to use. On the contrary, the introduction of the antiseismic filter between the supporting ground and the whole supporting structure is a delicate job for specialists.

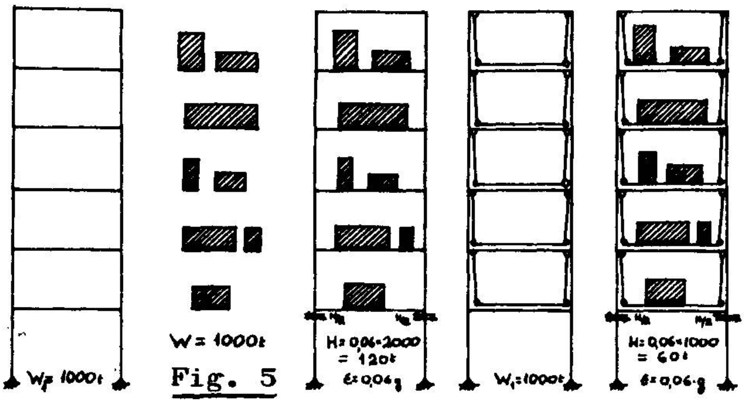


Fig. 5

NOTE A : There should be no confusion between 1) a heavy mass resting upon an antiseismic filter or an elastomer-layer, and 2) a suspended bridge; because the suspended bridge: a) does indeed oppose the horizontal motion of the piers upon which it rests or from which it is suspended, and b) it is a complicated elastic system that behaves quite peculiarly when it is set into motion. Therefore we will not say that a suspended bridge is untouchable by seismic effects just because it is "suspended". Of course, we can always introduce the antiseismic filter between the piers and the desk of the suspended bridge, or between the piers and the supporting ground, in order to modify or attenuate seismic effects upon the bridge; but this is a different question.

NOTE B : A water tank completely filled up and closed, behaves like a rigid body which is rigidly connected with the supporting structure. Seismic motion affects the whole mass of the water contained in it, and the corresponding seismic thrust is produced to act upon the supporting structure. But in a partially filled water tank the mass of water does not oppose the motion of the supporting structure, because this mass of water is free to move. Therefore, depending on the condition that the walls of the water tank are strong enough to resist any minor shock from the water contained in it, a partially filled water tank is practically untouchable by seismic effects. Therefore, in seismic zones we must leave empty an adequate free space within every closed water tank for the water to move in easily. In other words: in seismic zones, all closed water-tanks must be partially filled. The same conclusion is equally true for all closed fluid tanks, whether they contain oil, petrol or wine. I have been told that for chemical reasons the containers of certain fluids must be completely filled up; in any similar case, a light and weak cover will be built to separate the mass of the fluid from the free space within the container.

When we have done everything that is possible in order to lighten the weight of the structure by removing heavy masses or by isolating them from the supporting slabs, then we start thinking about the proper way of facing the seismic effects that are expected to act upon this structure.

The most simple way of calculating the seismic forces that are expected to act upon the structure is the following: we admit that 1) the motion of the ground is given by the equation:

$\ddot{x}=c$ for $0<t<t_1$; $\ddot{x}=-c$ for $t_1<t<t_2$; $\ddot{x}=c$ for $t_2<t<t_3$; $\ddot{x}=-c$ for $t_3<t<t_4$; $x=c$ for $t_4<t<t_5$; and so on, for the very small intervals $0\rightarrow t_1$; $t_1\rightarrow t_2$; $t_2\rightarrow t_3$; $t_3\rightarrow t_4$; $t_4\rightarrow t_5$; etc. and 2) for each floor of a multistory building, the whole structure below this floor makes an undeformable body that follows exactly the motion of the ground while the whole structure above this floor makes an undeformable body that m u s t follow exactly the motion of the ground. Therefore, the complete set of all structural members that connect the upper part of the building with the lower part of it, must exert upon the upper part of the building a seismic thrust equal to the product : (the weight of all masses rigidly connected with the upper part of the building) x (the acceleration of the ground). This is clearly shown in the analytical series of drawings in Fig. 6. In the case (a) the seismic thrust acting upon the columns of the ground floor is: $H_1 = m_1.c$, because ABB_1A_1 is assumed to be undeformable and the columns of the ground floor are assumed to be practically undeformable. This last assumption is equivalent to assuming that the moment of inertia of the cross-section of the columns is very large.
In the case (b) the seismic thrust acting upon the columns of the first floor is: $H_2 = m_2.c$, because ABB_2A_2 , which was assumed to follow exactly the motion of the ground, i.e. to move with the acceleration c, is assumed to be undeformable, and must follow exactly the motion of the ground, i.e. it must stop now! because the ground stops at this moment , and the columns in the first floor are assumed to be practically undeformable.
In the case (c) the seismic thrust acting upon the columns of the second floor is: $H_3 = m_3.c$, because ABB_3A_3 , which was assumed to follow exactly the motion of the ground, i.e. to be motionless at $t=t_1$, is assumed to be undeformable and must follow exactly the motion of the ground, i.e. it must move now with the acceleration (-c) because the ground moves now with the acceleration (-c) and the columns in the second floor are assumed to be practically undeformable.
In the case (d) the seismic thrust acting upon the columns of the third floor is: $H_4 = m_4.c$ because ABB_4A_4 , which was assumed to follow exactly the motion of the ground, i.e. to move with the acceleration (-c) , is assumed to be undeformable and must follow exactly the motion of the ground, i.e. it must stop now! because the ground stops at this moment and the columns in the third floor are assumed to be practically undeformable.
In the case (e) the seismic thrust acting upon the columns of the fourth floor is: $H_5 = m_5.c$, because ABB_5A_5 , which was assumed to follow exactly the motion of the ground, i.e. to be motionless at $t = t_2$ is assumed to be undeformable and must follow exactly the motion of the ground, i.e. it must move now with the acceleration (c) , because the ground moves now with the acceleration (c) , and the columns in the fourth floor are assumed to be practically undeformable.
We continue in the same way until all the upper floors are taken into consideration.

CONCLUSION: In order to calculate the seismic thrust we multiply the weight of any mass rigidly connected with the supporting structure by the acceleration (c) assumed for the ground, and consider this seismic force to act at the centroid of the object under consideration.

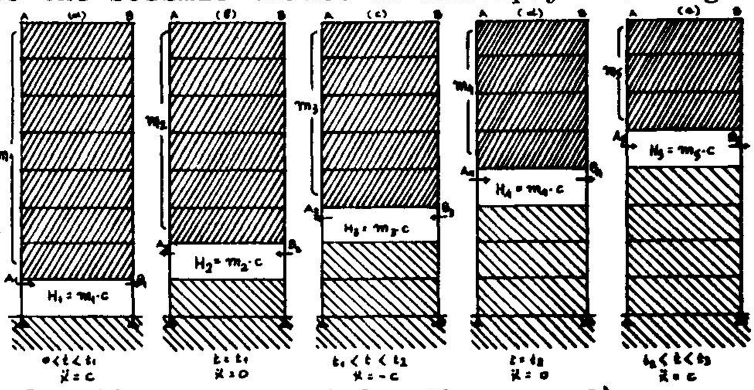


Fig.6

Therefore, it is very important to remember that the identification of seismic effects upon a multistory building with seismic forces that are equal to the product : (acceleration c assumed for the ground) x (weight of each mass rigidly connected with the supporting structure), acting upon this building, is not equivalent to the replacement of seismic effects by equivalent wind-forces in a static way. As a matter of fact, any similar identification is quite irrational and meaningless, unless it comes out as the result of a dynamic consideration of the motion of the building when the motion of the ground is given by the equations: $\ddot{x}=c$ for $0 < t < t_1$; $\ddot{x}=-c$ for $t_1 < t < t_2$, etc., but not by the equation $\ddot{x}=c$ alone. That means that this identification is always implicitly connected with a very rapid change in the value and the direction of the seismic motion. Therefore, it is always implicitly connected with a very rapid growing and vanishing of seismic forces.

Therefore:

We keep clearly in mind the assumption that the seismic forces acting upon the structure vary with extreme rapidity both in value and in direction; for this assumption we determine the seismic forces in the following way: Every mass rigidly connected with the supporting structure is acted upon by a horizontal force which is equal to the product of this mass by the value of the acceleration of the ground.

As soon as we have determined these forces, we try to build the supporting structure that will be able to resist them.

THE TECHNIQUE OF BUILDING THE SUPPORTING STRUCTURE THAT WILL RESIST THE SEISMIC FORCES THAT ARE EXPECTED TO ACT UPON AN OLD BUILDING

As a rule, all multistory buildings contain a supporting structure made out of reinforced-concrete, prestressed-concrete, steel or wood and including vertical columns and horizontal slabs. Therefore, as a rule, the existing supporting structure has the form shown in fig. 7.

This structure risks to have some columns broken, because they were not initially built to resist important bending moments. But now important bending moments due to the seismic forces are produced at the extremities of each column.

I have presented adequate methods in order to increase the resistance of old columns to additional bending moments./ I/,/ 2/ These methods can be used here if only a small number of columns in the whole building need strengthening. But if the large majority of the columns of the whole building need strengthening, then it is much easier and more economical to modify the supporting structure as shown in the Fig. 8. That is: in each and every floor we build the structure shown in Fig. 9.

Sometimes it is not possible to build the X-form connections, because these will obstruct a door or a window. In that case we build the connections as shown in the fig. 10, the values of q, q', r and r' depending upon the position of the door or the window.

The old supporting structure enriched with the oblique connections makes a space-truss. We use traditional methods of statics in order to determine

the value of the pulling force induced in every oblique connection, the axial force induced in every column and the axial forces induced in every slab.
As a rule, this computation will reveal that the slabs and the columns are strong enough to resist additional stresses due to seismic effects. If by any chance a column is found out to be weak, we can always strengthen it by using the technique introduced by my paper that I presented in Budapest. /11/ Therefore, the whole technique that we must present now consists in the proper construction of the oblique connections.

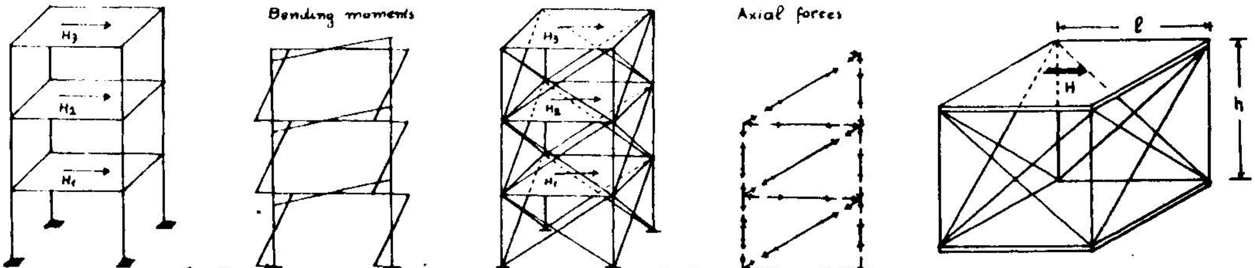


Fig. 7 Fig. 8

NUMERICAL EXAMPLES:
1) For the structure shown in fig. 19 we have the values H = 25t, h=3,00 m ℓ = 10,00 m. The pulling force in each oblique connection is:

$$N = \frac{\sqrt{h^2+\ell^2}}{\ell}\cdot\frac{H}{2} = \frac{\sqrt{5^2+10^2}}{10}\cdot\frac{25}{2} = 14^t$$

The axial force in each column due to seismic effects is:

$$\Delta P = \pm\frac{h}{\ell}\cdot\frac{H}{2} = \pm\frac{5}{10}\cdot\frac{25}{2} = \pm 6{,}25^t$$

and the axial forces in the slab is of course H = 25 t.

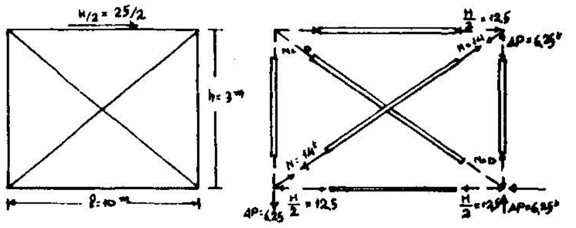


Fig. 9

2) For the same structure shown in Fig. 20 we have the values q=q'=45° and r=r'=60°. Under the action of the force H/2 the system of the oblique connections is deformed. There are two kinds of deformation: a) each triangle AGD and BKC is deformed; i.e. the angles r, r', q and q' change; and b) each triangle AGD and BKC rotates respectively about the joints D and C. For the deformation of each triangle we write the equations:

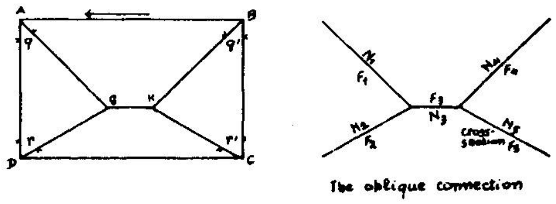


Fig. 10

for the triangle AGB: $\frac{AG\cdot(1+N_1/EF_1)}{\sin(r+\Delta r)} = \frac{GD\cdot(1+N_2/EF_2)}{\sin(q+\Delta q)} = \frac{AD\cdot(1+\Delta P_{AD}/EF_c)}{\sin(\pi-q-r-\Delta r-\Delta q)}$

For a realistic computation we put: $\pi-q-r-\Delta q-\Delta r = \pi-q-r$, $\frac{\Delta P_{AD}}{EF_c}\to 0$ & $\frac{N_1}{EF_1}=\frac{N_2}{EF_2}=\frac{2400}{2100000}$ assuming that we use high quality steel plates. Then we have the relation

$$1{,}00114\cdot AG/\sin r = 1{,}00114\cdot GD/\sin q = h/\sin(q+r)$$

These equations are written: $\sin(r+\Delta r) = 1{,}00114\cdot AG\cdot\sin(q+r)/h$; $\sin(q+\Delta q) = 1{,}00114\cdot GD\cdot\sin(q+r)/h$
whence we obtain the values of Δq and Δr .
In our numerical example it is: $AG\cdot\sin 45° = GD\cdot\sin 60°$ and $AG\cdot\cos 45° + GD\cdot\cos 60° = 3{,}00\ m$
whence: $AG = 2{,}70\ m$ and $GD = 2{,}21$. Then it is: $\sin(60+\Delta r) = \frac{1{,}00114\cdot 2{,}70}{3{,}00}\cdot\sin(60+45) = 0{,}8703$
whence $60+\Delta r = 60°\,30'$ therefore $\Delta r = 30'$. Similarly we obtain $\Delta q = 27'$.
for the triangle BKC:

We write similarly $\frac{BK\cdot(1+N_4/EF_4)}{\sin(r'+\Delta r')} = \frac{KC\cdot(1+N_5/EF_5)}{\sin(q'+\Delta q')} = \frac{BC\cdot(1+\Delta P_{BC}/EF_c)}{\sin(\pi-q'-r'-\Delta q'-\Delta r')}$

which is simplified into $1{,}00114\cdot 2{,}70/\sin(60+\Delta r') = 1{,}00114\cdot 2{,}21/\sin(45+\Delta q') = 3{,}00/\sin 75°$

whence we obtain $\Delta r' = 30'$ and $\Delta q' = 27'$.
Therefore the deformation of either triangle AGD and BKC is not really important.

Next we consider the rotation of each one of these two triangles with respect to the foot joint;of course the rotation φ is equal for both triangles.Fig.2I

First we write the equations for the static equilibrium of all the joints; so, we have:

for the joint A: $N_1 \cdot \sin(q+\varphi) \cong \frac{H}{2}$, $N_1 \cdot \cos q = \Delta P_{AD}$ for the joint D: $N_2 \cdot \cos r = \Delta P_{DA}$, $N_2 \cdot \sin(r-\varphi) = H_D$

for the joint G (let w denote the rotation of GK with respect to G):

$N_3 = [N_1 \cdot \cos(\frac{\pi}{2} - q - \varphi - \omega) + N_2 \cdot \cos(\frac{\pi}{2} - r + \varphi + \omega)]$ with $N_2 \cdot \cos(r - \varphi - \omega) = N_1 \cdot \cos(q+\varphi+\omega)$

for the joint K:

$N_3 \cdot \cos(\frac{\pi}{2} - r' - \omega - \varphi) + N_4 \cdot \cos(r'+q') = N_5$; $N_3 \cdot \cos(\frac{\pi}{2} - q' + \omega + \varphi) + N_5 \cdot \cos(r'+q') = N_4$

for the joint B: $N_4 \cdot \cos q' = \Delta P_{BC}$ for the joint C: $N_5 \cdot \cos r' = \Delta P_{CB}$, $N_5 \cdot \cos(\frac{\pi}{2} - r' - \varphi) = H_C$

After that we consider the static equilibrium of the whole truss ABCD in the horizontal direction: $\frac{H}{2} + H_D - H_C = 0$

in the vertical direction: $(\Delta P_{DA} + \Delta P_{CB} - \Delta P_{AD} - \Delta P_{BC}) \cdot \cos\varphi = 0$

with respect to the joint D: $\frac{H}{2} h + (\Delta P_{DA} - \Delta P_{AD}) \cdot \ell = 0$

In this way we have established I3 relations between the I3 unknown quantities N_I ,N_2 ,N_3 ,N_4 ,N_5 ,ΔP_{AD} ,ΔP_{DA} ,ΔP_{BC} ,ΔP_{CB} , H_D,H_C, φ and w.

From these relations we obtain easily the system of the following 7 equations with the unknown quantities N_I,N_2,N_3,N_4,N_5, φ and w :

$$N_1 = \frac{H}{2} \frac{1}{\sin(q+\varphi)} \quad , \quad N_2 = \frac{H}{2 \cdot \cos r}\left(\frac{\cos q}{\sin(q+\varphi)} - \frac{h}{\ell}\right)$$

$$N_3 = \frac{H}{2 \cdot \sin(q+\varphi)} \cdot [\sin(q+\varphi+\omega) + \cos(q+\varphi+\omega) \cdot tg(r-\varphi-\omega)]$$

$$N_4 = \frac{N_3}{1-\cos^2(q'+r')} \cdot [\sin(r'+\varphi+\omega) \cdot \cos(q'+r') + \sin(q'-\varphi-\omega)]$$

$$N_5 = \frac{N_3}{1-\cos^2(q'+r')} \cdot [\sin(q'-\varphi-\omega) \cdot \cos(q'+r') + \sin(r'+\varphi+\omega)]$$

$$N_5 \cdot \sin(r'+\varphi) - N_2 \cdot \sin(r-\varphi) = \frac{H}{2}$$

$$N_2 \cdot \cos r + N_5 \cdot \cos r' - N_1 \cdot \cos q - N_4 \cdot \cos q' = 0$$

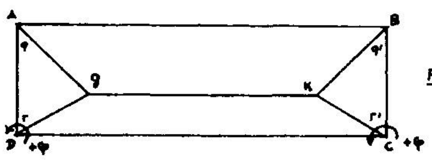


Fig. 21

For the values of the numerical example my assistants have obtained the following results: $\varphi \cong 15°$,$w \cong 0°$

$N_I \cong 13t$; $N_2 \cong 5,0t$; $N_3 \cong 16t$; $N_4 \cong 7t$; $N_5 \cong 15t$; $\Delta P_{AD} \cong 6,5t$; $\Delta P_{BC} \cong 7,5$ t

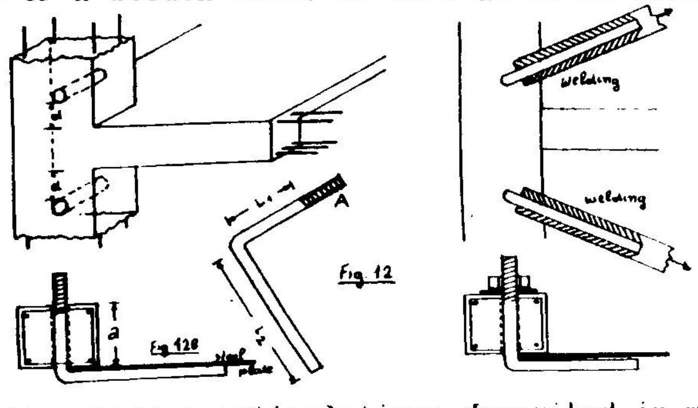
Attention should be paid to the fact that this form of the oblique connections is very deformable! The displacement of the head of the column with respect to the foot of it,is equal to $\Delta l = h.tg = 300x0,2679 = 80$ cm. Depending on the architectural form of the ground-floor,this large deformation is a big advantage or a big disadvantage.If the architectural finishing can endure this deformation,then this large deformation may be a big advantage,because it makes an efficient protection for the building against seismic shocks; but if the architectural finishing cannot endure this deformation,then we must chose the X-form for the oblique connections and place them along an inner partition-wall,where they will obstruct no door.The formulae given above hold equally well for the X-form connections, if only we put $w = \frac{\pi}{2} - q = \frac{\pi}{2} - r'$.

I think that we should always remember that the X-form oblique connections are simple and safe for everybody to use; on the contrary,the >—< -form oblique connection is a very delicate construction,that only a specialist should build.

The next step is to construct the oblique connections.

Now we must recall the following p s y c h o l o g i c a l fact,which, unfortunately is well established beyond any doubt,and universal:People are too prompt to forget the risk and the terror produced by earthquakes; then, when they start remembering it again, it is too late for any strengthening of old buildings! Therefore,if we really wish an old building to be strengthened against seismic forces,then we must make available a very simple and quick technique.Otherwise,strengthening of the building is postponed and finally forgotten.

The technique presented in this paper is so simple, that one can hardly think of anything simpler; and it is quite efficient.
We work in the following way:
1.- We make a hole at the head and at the foot of every particular column that makes a vertical member of the supporting space-truss. We try to make the distance (d) as short as the drilling instruments we can dispose of allow it. Fig. 22
2.- We bend pieces of strong rods of mild steel as shown in the figure. The length L_1 is a little shorter than the width (a) of the column. The extremity (A) is threaded to be ready for a nut. The length L_2 depends on the force that will act upon this rod; it must be sufficient for the welding of this rod onto the steel plate that makes the oblique connection .
3.- We place this piece of mild steel through the hole in the column.
4.- We use steel plates to construct the oblique connections. The cross-section of each steel plate depends on the pulling force that will act upon it, and on architectural requirements.
5.-We place the steel plates into position as shown in Fig. 22b, and
6.-We weld the rods onto them.
7.- After that we screw the proper nut onto the threaded end of the rod, stretching it as much as we can, and then we weld the nut onto the rod.
That is all!
Of course it is strongly advisable to use a gusset and to place the oblique connections symmetrically with respect to the vertical axis of the column (i.e. to use a double oblique connection placed at both sides of the column) whenever this is possible.
NOTE: It is not necessary to fix the oblique connections upon the external columns of the building. Most often, it is much more convenient to fix them upon internal columns along a partition-wall which is not ever expected to be removed. In that case, as a rule, it is convenient to use a double oblique connection placed at both sides of the partition wall. This double oblique connection works much more efficiently than the simple oblique connection just described. In that case, instead of a threaded end waiting for a nut, we bend this end and weld it onto the steel plate of the second oblique connection.
When the supporting structure is made out of steel columns, the construction of the oblique connections is even easier, because then, all that we have to do is just to weld the ends of these connections onto the steel columns. But in this case it is strongly recommended to use double oblique connections and to place them at both sides of the steel columns./ 3/
For a wooden house we work as we do with reinforced-concrete columns.



The vertical acceleration of the ground:

All the things that we have said in the preceding pages refer to seismic effects produced by the horizontal motion of the ground. We must remember that earthquake produces sometimes vertical motion of the ground. I think that the best way to face seismic effects due to the vertical acceleration of the ground is to use the sliding articulations described in my paper that I presented in Liège. / 4/This technique is good for a new structure; we cannot use it in old buildings. But statistics comfort us with the realistic conclusion that it is quite rare for old buildings in seismic zones to be destroyed by vertical acceleration of the ground.

THE FOUNDATION

It is important to consider always the action of seismic effects due the horizontal motion of the ground,upon the foundation of the old bı ing.If the old building stands upon a network of foundation-beams or a general foundation slab,then we have no problem with the foundatio if the columns upon which we fix the oblique connections stand upon . lated footings,then we must strengthen the foundation,because the is ted footings will not be able to resist the horizontal thrust produc by the oblique connections.

There are two techniques to use for strengthening the old foundation

I) We remove the old floor that rests upon the soil and build a new ı inforced concrete slab that makes the new floor; this slab must enci tightly all the columns of the building and be strong enough to resi the axial stresses produced by the oblique connections.

Sometimes it is easier and more economical to build the new reinforc concrete slab upon the old floor.

I must say that this way of strengthening the foundation is efficien primitive.

2)A more subtle technique is the following:

.- we make a hole through each column just above the old floor;

.- we place a piece of rod of mild steel through it;

.- we place steel plates upon the floor between all the columns and the rods onto them;

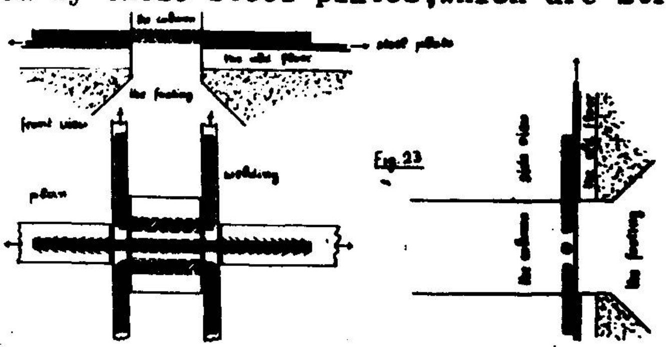
.- we place steel plates in the perpendicular direction upon the flo between all the columns;

.-we take proper auxiliary pieces of steel plates or rods and weld them upon second set of steel plates.

That is all!

If the steel plates must not protrude above the old floor even for o centimeter,then we make a one-centimeter deep trench and put the ste plates in these mini-trenches.

In this way we build a network of orthogonal steel plates that interc nect all the columns of the building.The seismic thrust induced in th oblique connections is resisted by these steel plates,which are stres to tension.



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