NOTES ON RECENT PUBLICATIONS RELATING TO THE EFFECT OF EARTHQUAKES ON STRUCTURES.

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The XIVth. Volume of Transactions of the Seismological Society of Japan contains an interesting series of Building Regulations and descriptions of the methods adopted in various countries as safeguards for dwelling houses against the force of earthquakes. It may be worth while to compare the conclusions which have been arrived at, as well as to see what deductions may be made from the general tenor of opinion, not only as regards houses, but also as to other structures, such as viaducts, etc.

That opinion may be sought in two different directions.

(1). From the practical experience of former generations who have lived in earthquake countries, and whose ordinary dwellings might be expected to embody such features as would enable them to resist earthquakes. "Ordinary dwellings" are defined as those erected by individuals on their own responsibility, apart from any regulations or supervision of the government of the country.

(2). From the Regulations of Governments; and from the results of scientific observation.

To speak of the practical experience first. If the resistance the house was to offer to an earthquake had been a primary object with its future inhabitant, it might be supposed that the same experiences would lead to the same conclusions, that is to the same type of house, even in widely separated countries, such as those which border the Mediterranean, South America, Manila, and Japan. For, the earthquake action being similar in all countries, the people in each country could only devise one best method to counteract it, and that method would be the same everywhere.

The houses in Japan are not unfrequently spoken of as if the type had been decided on with a view to some special anti-earthquake properties inherent in a structure of light unbraced vertical timbers, which rest on stones at the ground level and support a very heavy roof of tiles.

Regarded as a whole such a structure is simply an inverted pendulum which will swing through a certain angle and then turn over. Farther taking it room by room, the different parts of the building can give no support to each other. The Japanese type of house was probably adopted for other reasons.

As stone could not be obtained from the hills to build houses in the plains without enormous expense for transport over rough roads, and as the art of burning bricks was till lately unknown in this country the originators of the Japanese type of house had really only timber to use.

A wooden framing was forced on them, and the vertical posts were no doubt placed on stones to prevent the ends from rotting by contact with the soil.

It is not so easy to understand why the framing should not have included any diagonals, but it might be in order that there should be no obtruction to the free passage from room to room which is given by the wooden slides which serve as walls.

Tiles for the roof would be used because wooden shingles give but poor rain protection.

The above, if accepted as explaining the leading features in the ordinary house of Japan, would base those features on other considerations than the resistance to earthquakes, for which, except that the houses in Japan are of small elevation, no form of architecture would appear, *prima facië*, to be less adapted.

Nor could anything be further from either the Japanese or the best anti-earthquake type than the houses of South Italy as one finds them represented in Mallet's account of the Neapolitan earthquake in 1857.

He describes them thus:—

> "Loftiness, thickness of walls, apertures few but large, square headed windows, and arched doors and gateways, with heavy tiled roofs and deeply hanging eaves characterise the outside." . . . .
>
> "Limestone and brick are the staple materials."
>
> "The general style of construction of wall, even in first-class buildings, consists of a coarse, short-bedded, ill-laid rubble masonry without any attention to thorough binding whatever." . . . .
>
> "The houses are seldom under two stories and rarely exceed three."

Except that the heavy tiled roof appears common to the Japanese and Italian house there is no other feature in which they resemble each other.

Turning to another Mediterranean country, Mr. Manby wrote a paper to the Institute of Civil Engineers on the Granada earthquake in 1884, in which he thus speaks of the ordinary Spanish house:—

> "The poorer houses consisted of boulders laid in mud and the better ones of half baked bricks and plaster. Nothing was done to bond the walls or tie the structure together by properly secured timbers."

Both the above read as if the inhabitants of Italy and Spain had adopted a form of construction suited to the materials at their disposal, using rough masonry just as the Japanese use timber. The great difference seems to be that in Italy and Spain the house consists of strong material roughly put together while in Japan it is made of light material by good workmen.

As South America was colonised by adventurers from Spain one may suppose that these brought with them their own ideas of the kind of houses they wished to live in, and in the New World as in the Old that they carried out those ideas for themselves without regard to scientific considerations or government interference.

The absence of the latter in the form of Building Regulations is apparent in the last volume of our transactions, where the reports from Colombia, Ecuador, Venezuela, Mexico, and Guatemala are alike in saying that no such regulations exist.

In default of them each man will build his house as he chooses, probably in most cases in the fashion of his Spanish forefathers, and as to the houses in Spain we have had Mr· Manby's account.

From page 159 of our last volume it appears that in Chili and Lima there is a regular system, or systems, adopted, but that is a local one.

But no general system exists among different races exposed to the same danger in different parts of the world, and human experience, as such, has shown no concert of opinion in producing a type of house calculated to best resist earthquakes.

(2). To consider the regulations of governments, first in date of which are those of the Portuguese Government after the Lisbon earthquake is 1755, and the scientific investigations, which are the work of the present generation.

Both in the Government Regulations and in the suggestions of scientific men there are many points requiring most careful attention.

To begin with, one must realise, as clearly and simply as possible, what earthquake action means as a destructive agency; and then work out how best to counteract it. Such earthquake action as would be caused by a severe shock with a vertical, or nearly vertical emergence, must be left out of consideration, for it would destroy any building which could be made above it.

But omitting the above case of the origin of the force being immediately, or nearly, below the site of the structure, and assuming that we are dealing with earthquakes which act at an angle of 45°, or in most cases far less, with the horizon, we have then to think of wave motion on the earth's surface and of the recoil from this, as induced by the inertia of the building itself, after the wave has passed.

We know from Professor Milne's investigations that this wave motion varies, even at places adjacent to each other, according to the geological formation, and that it varies also at different depths, being found less at ten feet below the ground than at the surface.

The force may lie between very wide limits; it may be only such a quiver of the ground as all here are familiar with, or it may be sufficient to wreck even a solid structure.

But the latter event is rare, and to overthrow a well-built retaining or dock-wall by turning it over on its edge would require such a convulsion of the earth's surface as is seldom experienced.

The ordinary practice is to build such walls with good bond and of good materials, and more than this cannot be done.

To bring compound structures such as houses and viaducts as nearly as possible into the same category as simple structures should be the intention. And this would be carried out by so designing them as to prevent their component parts from separating.

If that can be done, then the building is secure against falling, except as a mass by overturning.

This is the question dealt with in the last volume of the Transactions by Monsieur J. Lescasse, by the Manila and Ischia

Regulations, and by Professor Milne, who has also contributed two papers on it to the Institute of Civil Engineers.

A building may be held together by ties, or by struts, or by ties and struts combined. Mr. Lescasse defines his object by proposing :—

> " To tie the masonry in piles or blocks connected together, so that neither the materials can be separated nor the walls broken."

From the drawing which he adds to his paper it is evident that he would carry out this proposal by a system of iron rods built into the walls, that is by ties only. But, on the vertical rods there shown, the strain would not be a tensile one, such as iron rods are suited to, but a bending or shearing strain. Therefore theoretically the rod is exposed to an action which it is not best suited to resist, and practically the Ischia Regulations contain passages equally opposed to this method. On page 138 we read :—

> " With regard to the value of iron ties, which, especially after the earthquake of 1881, have been proposed for several buildings, they have unfortunately during this last vertical commotion been shown not to have been very valuable, and in many instances they have created destruction, perhaps on account of their point of connection with the masonry not having been sufficiently complete."

Again, on page 153, we find in the same Regulations :—

> " The use of iron keys and bands possesses the drawback of excessively weakening the points of masonry which they touch and where they act, accelerating therefore often the destruction instead of preventing the same, especially when the movements are very intense, as is the case during strong earthquakes. The examples we had in Casamicciola in certain buildings near the bathing place, and in the already mentioned Villa-Di-Mayo, which has been completely destroyed, are of great importance."

From the above it is evident that the method of ties has not been found satisfactory under actual trial, and the directly opposite method of struts, that is of stiffening the house by wooden or iron beams, is that which all the governments which have given official attention to the matter unite in recommending.

We have in our last volume information as to the action of the Portuguese Government at Lisbon, of the Italian Government at Ischia, Norcia, and Liguria, as also of the Spanish Government at Manila.

Even though the making extracts from what this Society has so recently published must mean repetition, a few such extracts put consecutively may show how completely the Authorities who issued them are agreed.

Taking these government regulations in order of date for comparison, we have first those of 1755 for Lisbon. We have not these in full in the last volume, but on p.p. 157-158 they are referred to thus:—

> "The Barrack System was enforced. This consisted of a cage made up of timber beams so constructed as to be easily filled up with a coherent material, and limiting the number of stories above the soil to two." . . . . . . "The timber which was used was fir." . . . . . . "This new system of construction became customary, and people had such confidence in it that now, though the severity of the law has relaxed, barrack palaces of four or five stories are built."

The above is quoted from the Building Regulations for Ischia (1883), which go on to lay down similar rules for the dwellings in that island which were rebuilt after the earthquake which had then recently occurred.

Those rules are classed under two headings:—

"A." for Public Constructions.

"B." for Private Buildings.

In the first of these, after allusion has been made to the choice of site, to geological considerations, and to the desirability of one of the diagonals of the building being directed to the quarter from which earthquakes are most to be feared, we find the pith of the regulations in these words :—

> P. 166.—"As a rule for new buildings of a permanent character, whether these are of one or two storeys over the soil, the so-called "barrack system," with iron or timber frames, according to circumstances, so arranged as to solidly connect the frames of the floors with the truss of the roof must be adopted.

And again, when churches are spoken of :—

> P. 169.—"The system of construction of the walls which is to be preferred is the 'baraccato' with iron or timber frames, but in such case the columns between the naves must be of iron."

Also among "accessory articles" concerning details of construction :—

> P. 170.—"In barrack buildings having timber or iron frames, and especially in those of two storeys, in the frames of walls, between the beams of floors, and in trusses, a sufficient number of diagonal pieces for the formation of triangles which secure the rigidity of vertical and horizontal joints, as also that of the vertical and horizontal parts, must be used."

Turning to the heading "B" for private dwellings, we find the same intention in the paragraph :—

> P. 172.—"In dangerous zones and generally on very sloping ground, dwelling houses of one or two storeys over the soil, should they not be made entirely of timber, must be constructed according to the system of barrack houses with wooden or iron frames. Similar constructions must be properly strengthened by diagonals, so as to resist without variation shocks in different directions.

In the Manila Regulations, dated 1880, there are the following passages:—

"The vertical framework of private buildings can be excuted of iron or timber, giving to the wall pillars the necessary dimensions, and fastening the same together by means of diagonal braces, especially at the corners.

P. 115.—"Without prescribing timber for any class of frames the preference must be generally given to iron, as well for supports as for ties and frame works, especially taking care to make these rigid. The vertical frames must be of T iron or of lattice trusses, united as is customary."

P. 116.—"Rigid frame works of such material not only offer an absolute guarantee against disturbance during earthquakes, but they serve to strongly bind together the whole construction, giving to it unity, and procuring for the whole mass the necessary resistance against the motion of vibration, which the succession of motion makes a very essential condition, as it seems proved that in earthquakes there occur peculiar lines in which vertical vibrations reach an enormous power of projection."

From the above quotations it will be seen that the Governments of Portugal, Spain, and Italy, are unanimous in recommending that buildings should be stiffened by a framework of wood, or preferably of iron.

It might be worth consideration whether such a framework could be improved by the use of iron ties laid horizontally at the level of the ground and of the floors. Ties alone are objected to in the foregoing extracts from the Italian Regulations, but part of that objection rests on the disturbance of the bond of the wall by the rod, and this might be avoided by laying the rods in grooves cut in a stone plinth or string course.

To thus add ties horizontally to the barrack system would be to use a system of struts and ties. The cost of the latter would not be considerable, and their presence would aid in holding the structure together when exposed to horizontal motion.

With regard to roofs, all authorities appear to concur in thinking that the trusses should be strong and simple, well bedded on the walls, and covered with the lightest possible material so as to reduce top weight.

As to foundations, there is considerable difference of opinion as to how these should be made in soft ground, which is the most dangerous.

All agree in regarding hard ground, such as rock, as preferable, because vibrations are less felt through it.

But when it is necessary to build on soft material, which yields readily to the earthquake motion and transmits this fully to the building above it, various methods are suggested.

Lieutenant-Colonel Cortes in a paper based on his experience in Manila, regards deep foundations as useless and proposes:

> P. 222.—"The construction of a timber platform almost on the surface of the soil or at a very little depth, giving to this basement a wide extension in order to impart great stability to the building." . . . . . . "The whole platform has to form a solid and compact mass quite independent of the soil. However in order to avoid sliding, a limited number of fixed points connected with the soil must be established."

Such a foundation as Colonel Cortes there proposes is really a raft, a very useful and usual expedient for distributing vertical pressure on a weak foundation, but one which as regards horizontal pressures cannot be regarded as equally advantageous. If it were to be so, it would be necessary that the soft ground beneath the raft were absolutely fluid, so that there could be no cohesion whatever between it and the lower surface of the raft. But on that lower surface there must be cohesion, even with the softest ground, if only from the weight of the building pressing the raft down, and further the "fixed points" proposed by Colonel Cortes would give the ground a direct hold on the raft.

At the surface of the ground Professor Milne finds the maximum oscillation, which must pass directly into the raft and so to the building above, which would thus receive the full force of the earthquake.

In a work on the Earthquake of Ischia, published in 1885 by Dr. Johnston-Lavis, another idea is suggested:—

P. 101.—"The building should have its foundations replaced by a strong cohesive platform resting on a thick straturn of loose sand or pumice stone." . . . .

"This should fill an excavation of considerable depth and of an area greater than that covered by the building. The principle involved is of course the using up of the earthquake energy in friction and crushing of each individua- particle, and, as regards the use of the pumice, the intercepl tion of numberless air particles."

The above may be briefly defined as placing a cushion under the building, so that the earthquake shock may be absorbed to some extent before it attacks the building.

This plan of using a "cushion" if taken, not in connection with a "strong cohesive platform" (that is a raft which derives its motion from the surface), but with a system of piles driven into the soft ground, would probably be very valuable.

In the diagram of the Tokio earthquake of March 20th, 1885, which Professor Milne gave to the 83rd Volume of the Proceedings of the Institute of Civil Engineers, it is shown that while the oscillation at the ground surface was considerable, there was hardly any of it at the bottom of a pit 10 feet in depth. There is no difficulty in driving piles as far as that, or twice as far, in ground even moderately soft, and if the bearing of the building on the ground—and therefore the point of contact and application of force—can be taken down so as to receive the shock where the intensity of this is so much less, and if that diminished intensity can be further reduced by passing it in to the building through an elastic material between the bottom and top of the piles, the building would be affected by only a part of the wave motion which the earthquake projects along the surface of the ground. This is what Professor Milne has advocated as "deep and free foundations," and, not only for houses but for all buildings, it would appear most likely to ensure safety.

The buildings, other than houses, churches, or public edifices, all of which resemble each other to some extent, which may be considered with a view to the effect of earthquakes upon them, are arches and viaducts. And of the latter, only those which have not a steel or iron superstructure of girders, but are a succession of arches.

Some attention has been given by Professor Milne, in his papers to the Institute of Civil Engineers, to the subject of arches, but only to such small arch openings as are made in house-building over doors and windows.

He finds that these frequently give way, and usually at the springing of the arch if this is at a sharp angle with the wall.

The failure of such arches is no doubt due, not to the arch itself breaking, but to the mass of brickwork on each side the opening pulling the arch in two.

On a section line taken vertically through an average house wall it will be seen that where it is not pierced by window openings, one above the other, there is about three times the amount of material that there is on a parallel line taken through the openings.

On the unbroken line there is so much more mass, and therefore inertia, that it will rock in different time to the portion which is pierced for the windows, and this latter, having these more solid masses on each side of it, will be torn asunder by them.

In a viaduct, when the shock comes in the most unfavourable direction, that is at right angles to the piers, each arch receives a tensile strain in the direction of its length as the piers oscillate.

And to resist this tensile strain, or pulling in the direction of its length, the arch has only the tensile strength of the mortar, or the adhesion between mortar and brick or stone.

If bridges or viaducts are of great height the same disproportion as in the walls of houses will be found on section lines taken vertically, one through the abutment or pier and another through the centre of the arch. But when the height of the structure above ground is not great the mass of material in the pier is reduced in proportion, while the arch itself is always of much greater strength, as regards sectional area, than the few bricks set on a curve over a window opening.

In such works as these there is not the same discrepancy between the arched and the solid portions, and it is probably owing to this reason that failures are comparatively rare.

To what extent they have actually occurred we do not know and it would be interesting to investigate how far the old Roman viaducts in Spain, Italy, and the South of France have been affected by the earthquakes which have visited those countries during the centuries which have passed.

Modern Civil Engineering is still so young that its works have not yet had time to undergo the trial, but the old works round the Mediterranean have undergone it, and one of them, the great viaduct carrying the military road at Campostrina was found uninjured by Mallet (p. 94) when he investigated the destruction caused by the Neapolitan earthquake in 1857.

> P. 111.—"The Bridge of Spain has only suffered a slight imperfection in the arch, depressed to $\frac{1}{11}$., the other five stone arches where the elevation is a fifth of the span ($\frac{1}{5}$) having remained in a good state."

And on the following page the Committee proceed to say:—

> P. 112.—"They do not hesitate to guarantee that stone

walls where they are of little elevation, when they have a thickness adequate to their height, and principally when they are well constructed . . . can be used without danger.

This last extract may be taken as applying to the piers of a viaduct. As to the intervening arches, if they can be built with good material, strengthened as regards tension by the use of hoop iron laid between the courses, and curved into the abutments according to Professor Milne's suggestion, there is no reason why they should not be regarded as proof against the action of any earthquake they are likely to encounter.

Special care with the foundations would of course be necessary if the ground were soft, as in the case of houses.

A structure of this kind is a more homogeneous one than a house where the thickness of the wall bears but a small proportion to the width of the rooms, and the thickness of the floors a still less proportion to the height of the rooms.

For engineering works the dictum that arches should never be used above ground in an earthquake district should be modified by a consideration of the force of the earthquake liable to occur in that district, and also of the strength which can be given to the arches by careful designing and workmanship, so as to enable them to stand against that force.

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