Building in Earthquake Countries.

BASED ON THE RESEARCHES OF PROFESSOR MILNE.

THE recent earthquake in San Francisco which has resulted in such widespread disaster will again draw the attention of scientific and practical men to the consideration of the right principles of building in earthquake countries. It will be, therefore, useful to give a synopsis of the opinions and experience of those who have studied the question in countries most subject to seismic disturbances.

In Japan the dwelling is built ostensibly to withstand shocks but practically it is found to be the most unstable structure directly these occur of any violence. Built without foundations, a heavy tiled or thatched roof is supported by slender wooden uprights, which rest on flat stones level with the surface of the earth. The space between the uprights is filled with fragile sliding panels, across which translucent paper is strained. Many of the oldest of the temples and castles have withstood repeated shocks without sustaining injury. In the case of the castles they are protected by deep, broad moats, which break the earthquake wave; the older temples, though constructed on the same principle as the Japanese house, have, owing to their mass and rigidity, withstood shocks well. European brick buildings mostly suffered severely in the great earthquake of 1901. The cotton-spinning factory at Dembo, in Osaka, a new three-storied building, the cotton-spinning factory and the post and telegraph stations at Nagoya, collapsed at the first shock. These were, however, so slightly built that they were barely as substantial as would be deemed necessary in lands which do not quake.

Professor Milne is well known as a seismologist, and his accurate prediction, from Shide, in the Isle of Wight, of the time, extent and position of the last earthquake in India, has created such a great impression that his opinions on all subjects connected with earthquakes are being eagerly sought after. He lived for many years in Japan, where he held the post of seismologist to the Japanese Government, and where he had a unique opportunity of making observations of seismic disturbances, as in Japan it is estimated that there are on an average more than five hundred earthquakes a year. Turning his attention, a few years ago to the practical solution of the question how to lessen the disastrous consequences of earthquakes by observing the principles and methods of building which would ensure the least amount of suffering and destruction when earthquakes shake the land, he collected, with great industry, the experiences, and collated the building laws, of earthquake countries—of Italy, Manila, Spain and California —and throwing on these the light of his own careful observations he produced a report of the greatest possible value. Dividing his subject methodically under headings, he considered first the important question of—

1. *Foundations.*—As the result of observations made in a pit about ten feet in depth, it was found that the motion at the bottom of the pit was, in strong earthquakes very much smaller than upon the surface. These observations led him to the conclusion that great advantages might be gained by giving a building a deep foundation, this advantage being increased if the building rose freely, as in a house with an open area and a basement. That there is at least no harm in such a structure is attested by the fact that in all earthquake countries under building regulations cellars or basement archwork are recognised as admissible. That relatively little motion enters a building with such foundations is also attested by the fact that in cellars vaulting is allowed whereas for stories above the ground floor it has invariably been suppressed.

The Ischian regulations provide that buildings should be founded on the most solid ground. If, however, the ground is soft, a platform of masonry or cement should be formed, which, for a one-storied building must be 0.70 metre (2.30 feet) thick, and for a two-storied building, 1.20 metres (3.94 feet) thick. This platform must extend from 1 to 1.50 metres (3.38 to 4.92 feet) beyond the base of the building. In Manila it is stipulated that the foundations must be able to bear at least twice the weight that is to be placed upon them. When the soil is soft it must be piled or consolidated by a bed of hydrulic concrete, and the foundations of a building must, so far as possible, be made continuous.

Another method of minimising the motion received by a building is to give it free foundations. As an example of this, Professor Milne mentioned a room attached to his own house, in Japan which rested at each of its pillar-like foundations upon a layer of 4-inch cast-iron shot, between two iron plates. Short rollers, placed at right angles, might be equally effective. This building stood for many years. It was not disturbed by typhoons, and at the time of an earthquake a seismograph inside the building showed relatively to one outside but little motion. Cast-iron balls or shot, if they are only 1 inch in diameter, cannot be used, as they are wanting in frictional resistance, and the building is therefore subject to movements produced by winds and other causes. Professor Milne does not bring forward this building as an example to be followed in ordinary practice, but only as an illustration of a principle which may have practical applications.

The ordinary Japanese dwelling-house rests loosely on the upper surface of boulders or stones planted in the soil, and therefore it is difficult to conceive how it can receive the whole of the motion imparted by the shaking ground to its stone foundations. In temples and other large buildings with heavy roofs, which are common in Japan, there is usually beneath the supporting timbers and the superstructures a multiplicity of timber joints, which at the time of an earthquake yield, and therefore do not communicate the whole of the motion from below to the parts above. In the great earthquake of Ansei, in 1855, the whole of the buildings it is said remained intact. Certain roof of considerable span, in the Engineering College, at Toranomon, in Tokyo, were built so that they rested freely on the supporting walls, the object being that they might be free, so far as possible, on the wall which moved beneath them. Although they have experienced many tolerably severe shakings, hitherto they have remained uninjured. These examples show, especially for horizontal components of motion, that if a small building is not firmly attached to its foundations, or that if parts of a building have connections between them that readily yield, it is difficult to cause such a building to move or swing, and that by a proper application of this principle destruction may be, and has been, avoided.

Loose foundations might possibly be employed for small, light buildings erected on soft ground. For ordinary dwelling-houses, and especially for heavy structures, covering a considerable area, Professor Milne is inclined to the opinion that solid continuous foundations in the hardest ground and, if possible, surrounded by a free area, are the best. The objection to loose foundations for a large building is that different parts of the same building do not simultaneously receive momentum in the same direction, and also in severe earthquakes there is an actual wave-like motion of the ground.

2. *Archwork.*—An ordinary arch is undoubtedly stable for vertically applied forces, but for horizontal stresses it is most unstable. Archwork has so often been the cause of ruin, when shaken by an earthquake, that in Italy and Manila special rules have been drawn up respecting such structures. Thus, in Manila intersecting vaults are not allowed, and ordinary vaults are only permissible when strengthened in a particular manner by iron. In Liguria vaults can only be used in cellars, but even there the rise must be at least one-third of the span. The law of Norcia also only permits the use of archwork in cellars, and the thickness and method of construction are defined. In Ischia archwork with a rise of one-third of the span, and with a thickness of 0.25 metre (0.82 foot) at the crown, may be used, but only in cellars.

Speaking generally, the use of archwork above ground has been prohibited, and if it has existed after an earthquake, all governments who have paid attention to building have ordered its removal. Underground its use is permitted provided the arches are not too flat. This, however, only indicates that the motion beneath the surface is too small to destroy even a bad form of structure, and therefore such a form, if it be underground, is allowable. If for architectural reasons, it is a necessity that arches should exist, they should not be too flat, they should have a specified thickness, be protected by an iron or a wooden beam, and curve into the abutments. The Ligurian regulations provide that above windows there shall be two iron bars.

3. *Doors and Windows.*—In the building regulations for Norcia and Ischia it is stated that openings should be placed vertically above each other. It appears that if a series of openings like doors and windows in a wall be placed vertically above each other, it is much as if the wall had here and there been built with the joints of a line of bricks or stone continuing above each other, that is, the uniformity of the wall has been destroyed by lines of weakness, which will readily give way to horizontally applied stresses. An important point mentioned in the Ischian law is the position of doors and windows relatively to the freely vibrating end of a building, the limiting distance being 1.50 metre (4.92 feet). Similar provisions are found in the regulations for Norcia and Liguria. This distance should, if possible, be made to depend upon the materials of which a wall is constructed, its dimensions and the size of the openings.

4. *Chimneys.*—An important point, which constructors should keep before them, is to avoid coupling together two parts of a building having different vibrational periods, or else to couple them together so securely that they shall move as a whole. In Europe the first writer who recognised the fact that builders often allowed one portion of a building to destroy another, in consequence of their non-synchronism in vibration, was Bertelli, who mentioned the matter in 1887. The same subject has, however, been written about, experimented upon and emphasised in Japan, since 1880. In that year most of the wooden bungalows in Yokohama lost their brick chimneys in consequence of the wooden framing of the house swinging against them and cutting them off. By itself a chimney may stand, but when partially attached to a house, the house and the chimney are mutually destructive. The rules regulating the construction of chimneys are but few. The Ischian law states that they should be isolated from the walls; that of Liguria that they should not be in the walls, not connected with the building, and low. Chimneys not being much required in Manila nothing is said about them. Experience in Japan has taught householders to build their chimneys as short and thick as possible, to allow them to pass freely through the roof, and not to load them with heavy coping stones.

5. *Connection Between Different Portions of a Building.*—This leads to a consideration of the advantages to be gained by tying the different parts of a building together so that they shall vibrate as a whole. Since time immemorial buildings have been tied together with iron or with wooden rods, but some time previous to 1868, when San Francisco was shaken, a patent known as the Toye patent was taken out to improve the construction of sea-walls. This was made to apply to land structures. The City Hall and other buildings in San Francisco were built upon this plan, which consists in tying together the walls at each floor by transverse and fore and aft rods of steel or iron. A plan similar to this is that of Mr. J. Lescasse. It has been applied to several buildings in Tokyo and Yokohama. In such earthquakes as these buildings have experienced, they have stood well, excepting on one occasion when the chimneys of the German hospital in Yokohama were more or less injured. The system, however, requires to be thoroughly executed, for if the rods be too few, or if the bearing surfaces be too small, rather than support a building, they accelerate its destruction, especially at the points of contact. Such buildings, partly for this reason, and partly on account of their expense, are not looked upon with favour in Italy. The Ischian law specifies that if iron bands or chains are used, they must act upon a large surface.

6. *Roofs.*—The advantages to be gained by making the upper portions of any structure light are very great. When a building with a heavy roof is suddenly moved forward, the roof by its inertia tends to remain at rest. The result of this is conducive to a fracture between the lower part, which has been moved quickly, and the upper part, which has tended to remain at rest. In building regulations special reference is made to roofs, which must always be light, the materials recommended being iron or zinc, or felt, ordinary tiles being only permissible for buildings one story high, and not for habitations. Certain kinds of tiles have sometimes been regarded as permissible, but these require to be properly secured, and it is specified that in such cases there shall be a layer of planks above the ceiling. Tiles require to be especially well fastened near the eaves. The difficulty with roofs made of sheet metal is, first, to secure them from being disturbed during severe gales, and second to protect the interior of the house from heat. In Manila the first end is accomplished by a system of bolting whilst the latter is attained by a series of false ceilings.

The tiebeams of trusses should extend at least two-thirds across the thickness of the wall, and not over the whole thickness, and these rest upon wallplates. The form of truss recommended in Manila is the one with a central post (king post). For spaces greater than 7 metres (23 feet) iron should be used, and trusses must be so placed as not to act upon weak points in the walls. The Ischian law does not prohibit the use of flat roofs (*terrazzo*), but it provides that the framing of the same shall be strong and covered with materials which are fairly light. The Commission, who reported to the Government, however, condemned such roofs.

(*To be continued*).