Building in Earthquake Countries.

BASED ON THE RESEARCHES OF PROFESSOR MILNE.

SECOND PAPER.

IN our opening article in last issue we treated of the construction of foundations, archwork, doors, windows, chimneys, connection between different portions of the building, and roofs. We will now go on to consider other important points which Professor Milne so ably enlarges upon.

7. *Walls.*—Walls, like chimneys, should be light and strong. If heavy, and especially if loaded in their upper parts by copings and balustrades, they may be fractured and shattered by their own inertia. The height to which walls may be taken with safety depends upon the material of which they are constructed, the nature of the roof, etc. In Ischia it was suggested to limit buildings to two stories or a height of 7.5 metres (24.6 feet). The regulations, however, give 10 metres (32.8 feet) as a limiting height, if they are of simple masonry, and if of tuff, to a height of 4 metres (13 12 feet), with a thickness of 0.70 metre (2.30 feet). The committee suggested that external walls should be at least 0.30 metre (0.98 foot) in thickness, and that their uniformity should in no way be broken by openings for chimneys, pipes etc.

The Ligurian regulations allow three stories above the cellar, and a height of 15 metres (49.2 feet). The walls of the house, if it is not built on the barrack system, should be at least 60. centimetres (23.6 inches) thick. The Norcian regulations allowed two stories above the cellar and a height of 8.5 metres (27.88 feet). If a third story existed it was to be destroyed. The walls were to be thicker than ordinary, and their thickness was to vary with the material employed and the height of structure. In Manila masonry walls of ordinary dwellings only reach the first story, the upper story being of timber. The walls for public buildings however, may be higher. The regulations specify that the upper walls must not rest on a floor.

The length of a wall should not exceed twice its height unless supported by a buttress. The latter might be used at intervals not greater than twice the height of a wall Its thickness must be one-fifth of its height. Outside walls, transverse walls and buttresses must be well united, while the corners of buildings should be supported by buttresses. It would appear that the system of building with an upper story of wood resting on, and not built into, the supporting wall, and a light roof, ought not to do much towards ensuring the stability of a building. The weight of ordinary masonry may be reduced by the adoption of hollow brick.

8. *Balconies and Cornices.*—Many of the balconies or upper verandas in Manila were without support on their outer sides In such instances, their acting as loaded cantilevers within, either for horizontal or for vertical motions of the building, must cause considerable stress at their points of junction with the supporting wall. A careful examination of several hundred brick houses in Tokyo showed that the walls were usually cracked at the points where they were entered by the beams supporting a balcony, notwithstanding that the same balconies were supported along their outer face by vertical pillars rising from the ground Balconies in any form are objectionable features in a building constructed to withstand earthquakes.

9. *Shape and Orientation of Buildings* —In Liguria and Ischia the regulations provide that a building shall be rectangular in plan, and as nearly as possible square. Churches should be small and of the basilica form, with three naves, and iron columns between the naves. The Norcian regulations also recommend a square form.

In Ischia it was suggested that buildings should be placed so that the direction of the principal motion they were likely to receive should be along the diagonal of their plan. A result like this might be obtained by laying out the streets and roads in proper directions. Rossi suggested that the most resistant sides of buildings should be placed at right-angles to the nearest line of volcanic fracture, he holding the opinion that earthquake vibrations are propagated normally from the lips of such fractures.

The suggestion that buildings should be on a rectangular plan, or simple in shape, is worthy of consideration. It would certainly seem that such buildings would be subject to less destructive stresses than those largely built up of wings and other projecting parts, no two of which could be expected to vibrate in unison. Whether any great good may be gained by giving proper orientation to a building is not certain In Tokyo, walls extending in certain directions have been cracked more than others, and at the times of great earthquakes the destruction has been greater in streets running in a particular direction rather than in other directions. Streets ought to be wide, inasmuch as they would then form a refuge from falling debris.

10. *Floors.*—It was suggested in Ischia that floor-joists should rest with their whole thickness on the walls. If possible, joists should cross each other at right-angles, and the floorplanking be laid diagonally. Bertelli proposes a system of flooring of iron beams connected by brick vaulting, or in place of this, ordinary joists and planking. The beams on one story should be at right-angles to those on another. In all cases the joists are to extend completely through a wall. This regulation is also contained in the Norcian edict.

From these notes it appears that the intention of the authors of the regulations has been to utilise the floors to bind the buildings together as a rigid whole, and allow joists to extend so far into walls that there is no danger of their being drawn from their supports.

11. *Ceilings.*—Ceilings should be made in the ordinary manner with lath and plaster, but heavy ornamentations should be avoided.

12. *Staircases.* — Although staircases, if they are heavy, might prove a danger to walls, their construction has not been regulated by legislature. Bertelli suggests that they should be constructed of pieces bedded in the walls, as in the Tuscan system. If made by vaulting they are dangerous.

13. *Materials.*—In all regulations special stress is laid on the quality of materials employed, and in all cases it is specified that these shall be of good quality. The Ischian regulations specify that for the principal framework of buildings chestnut must be used. In all cases squared stones are to be employed. The lime must be good, and be properly slaked with fresh water. Below ground hydraulic mortar must be used, and the sand for the mortar must be clean. These matters are treated upon in all regulations. In the regulations for Manila there are special remarks condemning the use of liquid lime, and recommending that stone walls shall be kept wet while the mortar is setting, also that there shall be good bonding, etc.

14. *Types of Buildings* —The type of building most suitable for earthquake countries was discussed at considerable length by the commission summoned after the disaster at Ischia. The objections to iron buildings chiefly rested on their cost, the difficulty of keeping them cool and the fact that, as they were a novelty, it might be difficult to get them generally accepted. The commission, however, considered them durable and secure, and recommended that experimental buildings should be erected.

Timber buildings, although sufficiently strong and elastic to resist earthquake motion, and at the same time impervious to heat, have the objection that they are not durable, and are liable to take fire. These objections may to some extent be overcome by the proper application of paints and chemical preservatives. Mixed constructions of iron and timber were not considered to present great advantages over those wholly made of timber. Buildings may be made of iron or masonry either by covering an iron framework with stone or brick by building an iron framework inside the masonry walls, or by filling up the spaces between a double metallic framework with hollow bricks or other materials. Such buildings, although good from many points of view, have the drawback that they are exceedingly expensive.

Having considered these types, from which it will be observed ordinary buildings of brick and masonry have been excluded, the committee described a "barrack" system of building which is the system particularly recommended for Ischia. Briefly, such a building consists of a timber framework well braced together, the spaces between the timbers being filled up with hollow bricks, or some light material like scoria The timbering is hidden by rough cast. After the disaster in 1755 such a system was made compulsory in Portugal. A building of this type, which may be ornamented with an outside covering of tiles, is cheap, impervious to heat and safe against earthquake and fires. The suggestion respecting this system of construction was adopted in the regulations issued by the Government.

In the building regulations for Norcia the barrack system is the one to which preference is given. In the Manila regulations considerable latitude is allowed as to the system of construction ; stone walls are thought best, but concrete or brick is also approved of Although timber offers great resistance to earthquakes, its destructibility by fire, white ants ordinary rot, and its inability to exclude heat, prevent its recommendation. An iron framework, filled in with concrete, is spoken of with favour. In the recommendations of a committe appointed to consider building in Manila, stone was suggested for the basement and for the walls of the ground floor. This, with an upper story of timber, is the type of building common in Manila.

The Military Committee, which was summoned in connection with the destruction in Manila in 1863, pointed out that destruction had occurred in all classes of buildings, but that buildings with masonry supports had suffered more than others. This led to the suggestion that only one kind of material should be used in construction, and that masonry supports should be avoided. Private buildings should be of wood. In all cases the limiting spans of roofs were specified, and that the roofs must be light. Lieutenant-Colonel Cortes, who has written at some length on structures in earthquake countries, shows that buildings must be light as well as strong, and this may be obtained by binding their parts together, much in the same manner that the timbers of a ship are bound together. Foundations and walls should be continuous. Timberwork and masonry should not come in contact, otherwise they may be mutually destructive.

The Californian system of construction, for which a patent has been granted, appears to be very similar to that proposed by Mr. Lescasse, the essential feature in which is to tie a masonry construction together to each story by a set of iron or steel rods, which run from back to front in the interior of the walls of a building. There are also rods running vertically. From South America but little information was obtained. In Colombia the smaller houses are built of thick adobe bricks, while the Spanish stone is used.

In Equador (Quito) occasionally a special earthquake-proo room is built, the walls of which are of wooden framework, filled in with adobe. Many houses which have adobe walls 3 feet thick, have only one story, and there are few houses with more than one upper story. In Venezuela also, the houses are low. In Mexico and in Bolivia the houses are solidly built, while in Lima certain buildings are constructed lightly so that they may yield.

Having obtained a site, one of two general systems of construction can be followed, namely, either to give so much rigidity to a structure that it may be likened to a steel box, or to erect a light building which has so much flexibility that it may be compared to a wicker basket. Both these structures should be light, especially their upper parts. Buildings of the former class, which, from the materials entering into their structure, are unquestionably heavy, include ordinary structures of stone or brick (by preference, hollow bricks).

These should rise from a deep foundation, have a tree basement, walls of unusual thickness and be well bonded and tied together. The roofs should be light, and the precautions respecting the position and form of openings, the arrangement of floors, roof trusses and top weight referred to in the preceding epitome, should be carefully attended to. In this the strength of the building more than outweighs the ill effects due to its weight. Such buildings are durable and relatively safe against fire. They are suitable for all climates, but they are, in respect to all other buildings, exceedingly expensive. For this latter reason this type of structure can only be employed for buildings of importance.

Light buildings, which have sufficient strength and flexibility to overcome effects due to their own inertia when shaken by an earthquake, include nearly all well-constructed structures of wood or iron. The former, however, are neither durable, fireproof nor impervious to heat and cold ; but these objections may be practically overcome, and wooden buildings are cheap. Iron buildings are relatively expensive, and, without special arrangements, they are too hot in summer and too cold in winter.

A type of building which offers the same advantages as a brick or stone structure against the danger of fire, and in being suitable to resist changes of temperature, and which is also much cheaper and at the same time safe against all ordinary earthquakes, is the barrack system so strongly recommended in Italy. The framing may be of wood or iron while the filling-in which forms the walls, which ought to be as light as possible, may consist of hollow bricks or a concrete of light material To resist earthquake motion, lightness and strength are essential, and, if possible, a certain elasticity. Weight, unless it is accompanied by great strength, is a quality to be avoided.

For buildings of importance Professor Milne has suggested the use of brick. Let the buildings be placed in good situations, the brickwork well bonded and unusually thick, and let them rise from deep foundations. Roofs should be light.