AN ARCHITECT'S NOTES ON THE GREAT EARTHQUAKE OF OCTOBER, 1891.

By Josiah Conder, F.R.I.B.A.

In venturing to publish the following notes in their present form, the writer has been influenced by several considerations. Their revisal and re-arrangement more systematically would obviate the occasional repetition of similar observations and deductions in different places, but would, on the other hand, tend to over-generalising, and perhaps impart undue importance to the writer's own casual inferences. For a proper understanding of their value it is necessary that inferences and speculations should not be separated from the exact circumstances and conditions upon which they are based. Much ground has been lost in scientific investigation owing to too hasty speculation, and an uncontrollable tendency to adapt facts to preconceived theories. Conclusions arrived at by the present writer regarding the resistance to earthquake afforded by different methods of construction are altogether based upon his personal observations immediately after the convulsion. It is desirable, therefore, in placing them on record, that the different data upon which they rely should be presented in the regular sequence and under the exact circumstances in which they were observed.

With this aim the form of itinerary notes has been preserved. Purely phenomenal records, not bearing directly upon the subject of structures, have been purposely eliminated. It being the writer's object to record fairly, without prejudice to any style, the effects upon all classes of structures, care has been taken to avoid all exaggeration and sensational description which, though perhaps tempting instruments for arousing public attention to scientific matters, are inconsistent with patient and reliable scientific investigation.

Approaching the damaged districts by means of the Tokaido railway, the first signs of the earthquake's more distant effects upon buildings were seen in certain houses which had some of their plastering thrown off, and their ridge-tiles shaken down. These were observed at Washizu, and further on at Mikata-ga-hara and Toyohashi. (It may be here observed that the tiles of all Japanese roofs are simply laid upon clay spread over the roof, with a slight lap. The ridges consist of layers of tiles also jointed with clay and, in some cases, externally pointed with lime mortar.) In the same neighbourhood a farm-house, apparently very old, with a heavy thatch-roof, had completely collapsed. A stone image of the god Kwannon, balanced on the extremity of a rock pinnacle at Mikata-ga-hara, had remained standing, but some stone lanterns at Goyu had their top balls thrown off. The large circular brick piers of the railway bridge over the Tempaku river were cracked near the base, and the facing bricks loosened round the cracks.

Near Atsuta certain farm-houses had small moats with stone-faced escarps surrounding them which carried long out-buildings called *nagaya*. The *nagaya* and certain neighbouring "godowns" were observed to be leaning over out of the perpendicular. Riding from Atsuta to Nagoya in jinriksha it was observable that the majority of street houses had their posts leaning out of the perpendicular, and these were loosened from their sockets in the supported beams. The upper portions of these houses all bulged over towards the street; they were in most cases *attached* houses, and therefore supported by one another laterally. The upper floors had mostly fallen in, and the interiors were gutted; their tiles were all loosened, and many had fallen. These buildings, which were all out of equilibrium, were prevented from collapsing during the subsequent smaller shocks of earthquake by means of temporary strutting and shoring which was being busily constructed. Many isolated houses, not supported laterally by others, had collapsed, presenting a mass of beams, posts, mud, plaster, wattling, and broken tiles. Many stone monuments and lanterns were observed to be overthrown in *different directions*. The centres of the narrow streets were taken up by cabins and temporary erections made with wooden shutters, paper slides, and mats tied with straw ropes; in these the inhabitants were taking refuge, nearly all the buildings being tenantless.

Arriving at Nagoya, the brick buildings received first attention, their damage having been attended with the most serious results. The Post and Telegraph Office, a high brick structure of two stories, showed a large length of the wall of its upper story fallen from the cornice to the cills of the upper windows. The chinney stacks above the roof-line had crashed through the roof and upper floors, making large square holes through which some of the roof and floor timbers had fallen. The metal-covered roof and lantern, of triple span, belonging to a large Sorting Office, which roof was supported on four hollow cast iron columns, had fallen in, the outer wall being pushed out; but the columns remaining standing. One portion of the two-story building at the end of the South wing, which was divided by cross walls of brick, and tied across the top by means of a brick vault, had not fallen.

This building had been erected by a local firm of contractors, and was reported to have been completed at a price of six or seven thousand *yen* below the original Government estimates: it was about four years old. An examination of the structure showed that the outer walls of the lower story were two bricks in thickness and those of the upper story one brick and a half. The total height of the walls to the cornice was from thirty-two to thirty-three feet. There existed only a few cross walls which were of large span, one brick and a half thick below, one brick thick above, and placed about 60 feet apart. The remaining external walls were framed in wood, but they were few in number, and, for the most part, the building was divided into offices of very large size. The floor beams were of minimum dimensions, shallowly and loosely let into the brick walls, their ends resting on stone templates, wooden wedges and shavings being in some cases driven between the stone and the beams to give them a level bearing. The outer $1\frac{1}{2}$ brick wall of the upper story had large windows, and no piers or cross walls for a length of sixty feet. On inspecting the fractures of walls it was found that they had nearly all occurred at the mortar joints. In fallen masses of brickwork only the bricks receiving super-incumbent weight during the fall were broken. Perfect bricks were without difficulty detached from the brickwork, and such mortar as still adhered easily knocked off with a hammer, crumbling to powder in the fingers. An examination of portions of the walling still standing showed fissures in which the brickwork had separated at the mortar joints, leaving the mortar loose (see Fig. 1). In some cases the cakes of mortar in horizontal joints had been shot partially out, thus showing no adhesion to the bricks (see Fig. 1). In other

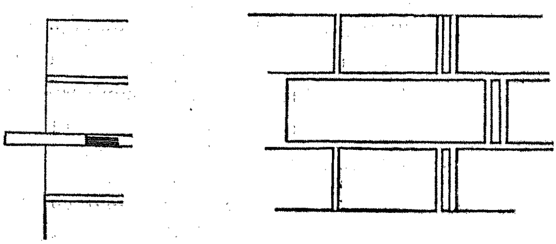


Fig. 1.

cases loosened bricks had been partially shot out (see Fig. 2). Also, the brick voussoirs of arches had been loosened at the mortar joints and had dropped (see Fig. 2). Remaining standing was a smaller secondary building for service, also constructed in brick, and of two stories, but somewhat lower than the main building, with walls of limited span, and having smaller windows. A projecting cornice of plastered brickwork had been forced out on the North side by the action of the roof; the tiles were loose, and the roof bent, but there were no other serious injuries.

Enquiries showed that most of the soil of Nagoya was red clay, with the exception of parts of the Citadel which had been filled in with made-ground excavated from the moats. The foundations of the Post and Telegraph Office building consisted of brick footings upon concrete trenches placed immediately upon the hard red clay.

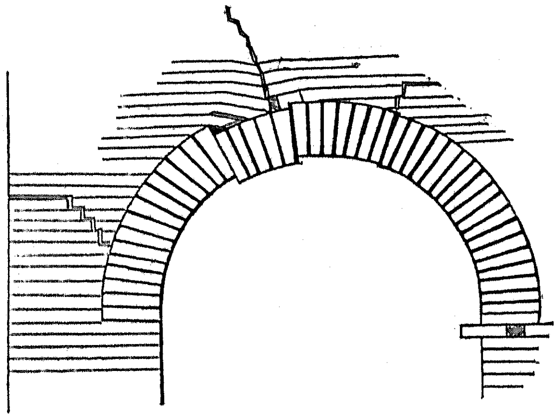


Fig. 2.

The most apparent defects in these buildings were as follow:—The thickness of external brick walls had been reduced to a minimum. Cross walls of brick were rare, and in some cases occurred only at distances 60 feet apart; these were also of minimum thickness. The outer walls of the upper story being one brick and a half in thickness had numerous large windows, reducing considerably the area of the brickwork, without piers or cross walls, and heavy granite dressings with little bond were added to these windows. Floors were loosely and defectively constructed. Important transverse walls and certain cross walls were of timber, roughly framed, without diagonals. The mortar was totally defective, having no cohesion in itself, and no adhesion to the bricks, being indeed but a little better than clay or mud.

The next brick structures examined were the Engine and Dynamo Hall and the furnace chimney of the Nagoya Electrical Lighting Company, erected by the Nagoya Kenchiku Kaisha. The hall measured about 50 ft. by 60 ft. and was of one story, with walls only about 18 feet high and one brick and a half in thickness, having small half brick piers, but no cross walls. The ends of the building were carried up in the form of brick gables. These brick gables had been forced out by the movement and vibration of the roof trusses and purlins (see Fig. 3). The main walls remained intact, showing only small cracks over the window arches.

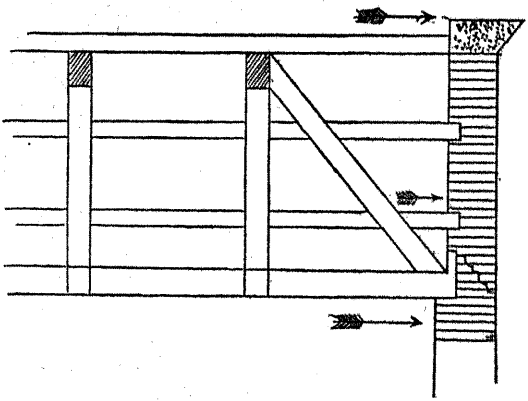


Fig. 3.

GABLE FORCED OUT BY OSCILLATING ROOF.

Narrow brick piers with heavy stone tops, forming the pillars of the outer entrance gates, had fallen in a N.N.W. direction, and showed that there was but little cohesion in the brickwork. (It was generally reported in Nagoya that the direction of the earthquake shock, as felt, was from S.S.E. to N.N.W.) About 20 feet length of the brick chimney, measuring in all 90 feet, had fallen, and the remaining portion was cracked to a distance about 18 feet below the fracture. There were fine cracks, horizontal and diagonal, near the base, but this lower part appeared safe.

Conclusions were :—That the cohesion and adhesion of the mortar used in these buildings was only slightly, if at all, superior to that of the Post and Telegraph Offices. For the rest, the methods of construction followed could hardly be considered defective from the point of view of ordinary stability and safety, considering the class of building and its commercial purpose. The walls, though of some length and moderate thickness, were low, wide between windows, and had small strengthening piers. On the other hand, the destruction of the brick gables by the roof timbers, and the breaking off of the chimney, pointed to the necessity of additional precautions in such portions of structures, as well as to the need of employing more cohesive and adhesive mortar when the possibility of violent earthquake had to be considered.

The next brick building inspected was the Shirei Hombu, or Garrison Office within the Castle grounds, constructed by the Nihon Doboku Kaisha from the designs of Mr. Tanaka Toyosuke. This was a building of brick and stone, of two stories, the outer walls measuring about 34 ft. in height to the cornices, being two bricks thick below, and one brick and a half thick above. Windows were of medium size with wall spaces considerably wider than openings. Cross walls of brick, one brick and a half thick below and one brick thick above, were placed at moderate intervals of from twenty to thirty feet; but there was a want of continuity in the upper brick walls, some being replaced by wooden framed partitions. Floor beams and roof timbers were substantially built, resting well into walls, but with no anchoring. All the walls of this building, with the exception of triangular pediments, remained standing. The brick pediments had been forced out by the roof framework and parts of the cornice thrust out by the tie-beams in the same manner as observed in the Electric Lighting Building (see Fig. 3). A small segmental central pediment was also pushed over. The chimney stacks had all fallen from the roof line, passing in most cases through the roof and floors and making large holes about 10 ft. square. One, which had not fallen, remained broken off and balanced, leaning over at the roof line. One chimney stack corbelled out near the top in a N.W. direction had fallen in a S.E. or exactly opposite direction. The centre key-stones of the flat heads to the stone window dressings had been loosened, and in some cases had nearly fallen out. In internal brick cross walls

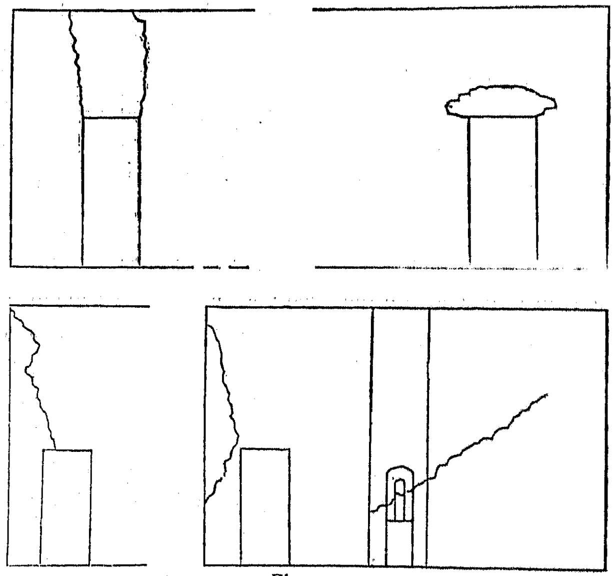


Fig. 4.

wide cracks had occurred near their junction with the outer walls, and other large diagonal cracks were observed running across these walls from the chimney stacks and top corners of the rooms (see Fig. 4). When seen by the writer, these cracks were large fissures a quarter of an inch or more in width, and gradually attenuating, but the evidence of people present during the earthquake should that only hair-cracks were formed after the first violent shock, which had since gradually widened during the subsequent frequent small shocks. A curious oval crack was noted over a doorway in a brick wall roughly corresponding with the line of the relieving arch and lintol (see Fig. 4). There were other instances of two vertical cracks extending from the top corners of a doorway to the ceiling. Internally, cracks were visible over all window arches on the upper floor. An examination of the interior of the roof showed it to be apparently in perfect condition with the exception of the holes made by fallen chimneys. It was of strong and substantial construction, with large ties and queen-post framework, having strong iron bolts. The joints of the timbers remained almost perfect, and iron straps and bolts were not twisted or loosened. The rocking of the roof had, however, shoved over the brick gables, cut off the chimneys, and pushed out parts of the stone cornices.

The outer entrance gates were of iron, with granite piers. Some of these piers had fallen, but one remained partially leaning over, propped up by the iron gate and showed that it had rotated from East to North as well as sliding in a N.W. direction (see Fig 5). The Gate Keeper's Lodge, a low brick building with walls one brick thick, remained standing, but showed a curious injury in one corner. Granite quoins, of straight joint with the brickwork, and occupying the whole thickness of walls, had been used at the corners, and one angle of such quoin work had been shaken out, leaving the ends of brick walls exposed and a daylight space between (see Fig. 5). The fallen granite blocks were in long vertical lengths and very rough on their backs and beds; they had formed, therefore, only a loose straight-joint with the brickwork. The conclusions arrived at from the inspection of this building were as follow :—

External brick walls, though no thicker than those of the Post and Telegraph Office, were better tied with cross walls, and the

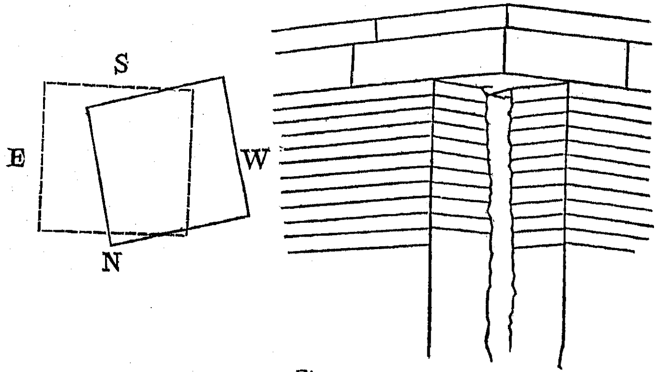


Fig. 5.

brickwork had been laid with more adhesive and cohesive mortar. The mortar was, however, still defective, not having the same cohesion as the common mortar employed in Tokio. Portions of this mortar were brought away for examination. Brick gables had suffered in exactly the same way as in the Electrical Lighting Building, though the roof was strongly and well constructed; also the tie-beams had pushed out the cornice. Such points called for careful attention in the future. The upper parts of chimney stacks above the roof showed the same signs of weakness as observed elsewhere. The cross walls had prevented the collapse of the outer walls, with which they appeared to have been fairly well bonded, but they were themselves too slight, and had suffered considerably under the strain, especially at the corners and over the openings. Very flat segmental arches, and flat stone lintols jointed as arches, had opened and cracked. Wood lintols over openings seemed to have done damage to the walls. Stonework was not properly bonded into brickwork, and large open cavities occurred behind the stone blocks.

In another part of the Castle grounds was a large Powder Magazine constructed in brickwork and externally plastered, which had received no injury whatever—not even the slightest crack. It was a one story building about 30ft. by 45ft., very strongly constructed, with walls $2\frac{1}{2}$ bricks thick and 20ft. high, and with no cross walls. It had not been built by contract but by day-work, under the special supervision of the Military Department. The foundations, as shown on the drawings inspected, were carried 5ft. below ground and consisted of a thick concrete bed with squared stone footings and continuous stone plinth above. The concrete had been laid on made-ground consisting of blackish earth, which had been first well rammed with a layer of broken stones.

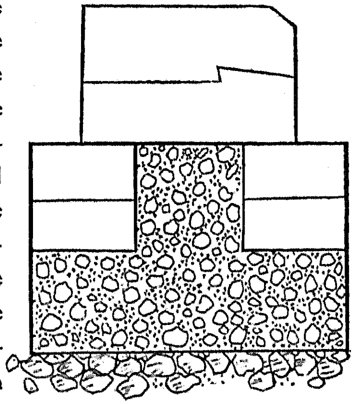


Fig. 6.

A curious method of notching had been used between the stones of the plinth, and concrete had been filled in between the rows of squared stone footings (see Fig 6). These unusual methods of construction seemed to the writer more attributable to amateur work than to any scientific intent, but as this was one of the only brick buildings in Nagoya entirely uninjured, the responsible authorities were inclined to take credit for these details, as if devised in view of earthquake. The notching of plinth stones might, as will be exemplified later, form a most useful expedient against the effects of earthquake in the case of stone bases to light wooden buildings, where a sliding between plinth stones could take place, but in a heavy brick building the advantage does not easily appear. Ideas of preventing penetration of damp between straight joints had most probably influenced the designer in this instance.

In addition to the great proportional thickness of the walls, the careful bricklaying, and good mortar which the specification showed to have been used, it must be noted, that, the building being a Store, had but very small openings for light, and the apertures in walls were therefore reduced to a minimum. The floor was strongly constructed, with brick vaults tying the structure at its base. The outside as well as the inside of the walls was plastered, the method employed being that of building numerous hanging hemp cords into the brick joints and plastering over these; so that with the most violent shaking the plaster was not cracked or thrown off. To give some idea of the solid and careful construction, it may be mentioned that this one story building, which covered an area of only 37 *tsubo*, cost 5,363 *yen* or about 145 *yen* per *tsubo*, though only a plain store-house with no ornamental stonework, cross walls, internal doors, or other details. This price represents a cost only 50 *yen* per *tsubo* less than that of the complicated two story offices previously described. It may be mentioned that quite near this Powder Magazine a curious phenomenon had taken place during the earthquake, a liquid white clayey sand, known by well diggers to exist below the surface at a minimum depth of 50 feet, had been squeezed up to the surface, spirting out of the ground, and the whole surrounding area was at present covered with this white deposit. This is worthy of notice as indicating that the safety of this particular building can hardly be attributable to any local immunity of the site caused by neighbouring moats, or rigid subsoil.

Near to this building another Magazine of wooden-frame construction, plastered over, and built on a granite plinth, had been considerably damaged. The roof was broken and the tiles were thrown off; also the plastering, and the clay rendering below which had been attached to bamboo wattling, was cast off in large pieces.

Close by was a Rice Store,—a long wooden building in the most solid ancient Japanese style of construction with thick timbers. It was old, and apparently the tenon joints and dowels were rotten. It was all pushed out, toppling over on one side, the other side being bent inwards.

In another part of the Castle grounds were to be seen the buildings of the Military Hospital connected with the garrison. These were separated blocks of one-story buildings of wood, in pseudo-European style, erected on a plinth formed of two courses of hard stone. One ward in the N.W. corner exhibited signs of very curious disturbance in the stone plinth, and between the plinth and wall cill (see Fig. 7). A rotation of the four corner stones of the upper plinth course had taken place, and in different directions.

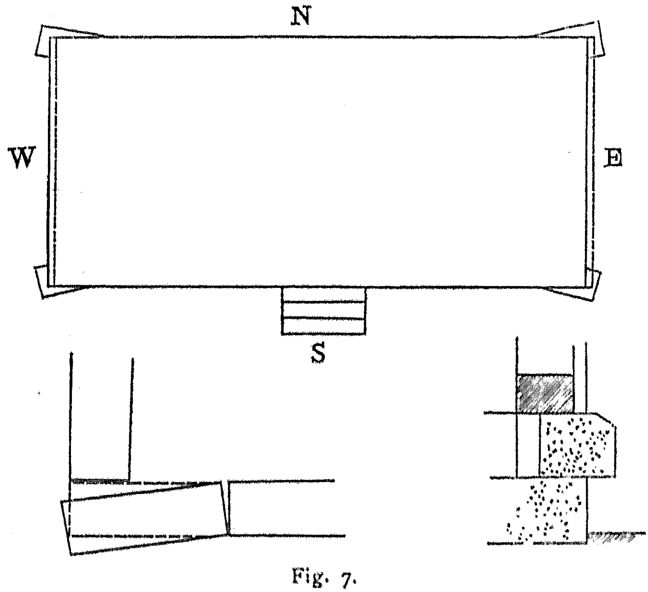


Fig. 7.

The bottom course, being partly bedded in the soil, had remained stationary, or rather followed the motions of the ground, but the whole of the upper course, together with the superincumbent wood-and-plaster building had been shifted a few inches to the West. This sliding movement had been registered by the stationary steps on the South side which were also bedded in the ground. In addition to this general sliding, the four corner stones had been forced out, as if by a centrifugal force, and, in one case, the corner block had dragged the second block partly with it. Conclusions drawn from these effects, and from an examination of the construction, were :— That the stones of the plinth had rough loose beds and backs and were imperfectly cemented together. The superstructure being light, and only laid upon the stone base, did not by its weight offer any considerable resistance to the movement that had occurred. A system of sinking or notching the wall plate into the plinth, and of notching together the different courses of the plinth, as adopted in the Powder Magazine referred to above, (see Fig. 6) would probably have prevented this movement. The writer is of opinion that even proper square beds and backs properly united with adhesive mortar or cement would have been almost sufficient to obviate the movement; but in this respect the conditions of light superstructures like the present one and those of heavy brick structures were somewhat different.

An examination of the Castle itself and the surrounding fortifications showed the following injuries :—Several parts of the stone-faced escarps of from 40 to 50ft. in height had fallen, together with their earth backing, and there were large cracks and crevices in the roads parallel to these slips, caused by the failure of lateral supports. In one of the small yards formed by the double gateway approaches and occupied by the military guard, the large square ashlars of the raised earthworks, had fallen on all sides, causing, it was said, a panic among the guard. The *Yagura* (corner turrets) and connecting *Tamon* (barracks) crowning some of these earthworks, built in the most solid Japanese feudal style, had their plaster cracked and in some cases fallen off. The turrets had tile roofs which did not appear injured. In another place a portion of a large barrack built on the extremity of a stone faced *doté* (earth mound) had collapsed, a part of the *doté* crumbling into stones and dust, and tearing the building off in the middle. A curious effect was observable in connection with the *Omotte Ichi no Mon*,—one of the principal gateways —the upper story of which consisted of a heavy wood-and-plaster structure spanning a space between two stone-faced embankments (*doté*), this space being occupied by heavy posts supporting the superstructure and forming the gateway. The heavy stone-faced *doté* on either side had by their movement squeezed and doubled up the slabs of granite-paving, as shown at A in Fig 8.

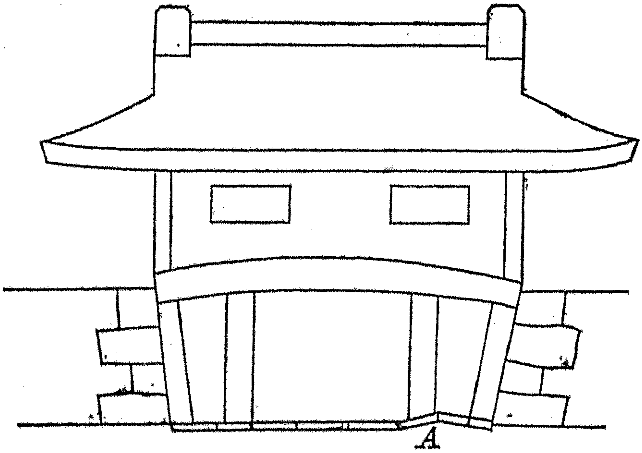


Fig. 8.

The Castle Palace (*Goten*) showed no external injury, but the internal walls were much shaken and cracked, and many of the mural pictures had peeled off the walls. A small treasury outside, built of slabs of stone placed vertically, and plastered over with a kind of stucco having pebbles mixed with the last coat, had cast off all its plastering, which seemed to have had no key or adherence whatever. In the case of a Japanese built *dozō* (mud-and-plaster godown) having a skeleton of stout wood-work, covered with wattling and, several coats of clay and plastering (in accordance with the usual construction of these Japanese fireproof stores), the whole of the clay and plaster work of considerable thickness had been thrown off, exposing the timbers of the framework below. This was interesting, as it offered an explanation of the statement often heard that at times of conflagration following earthquake the Japanese fireproof stores burnt like other buildings. A small wood-and-plaster annex to the main palace building, called *Yudono Shoin*, was leaning considerably out of the perpendicular.

A small one-story Gate Keeper's Lodge, built in brick in European style, with walls of one brick thickness, showed the portion of a window arch fallen out, but no other injury.

The *Tenshu*, or Keep, appeared not to be injured with the exception of a few ashlars of the stone-faced earthwork which

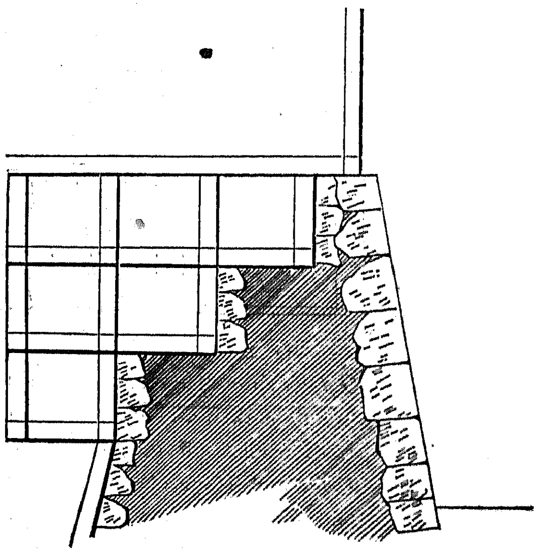
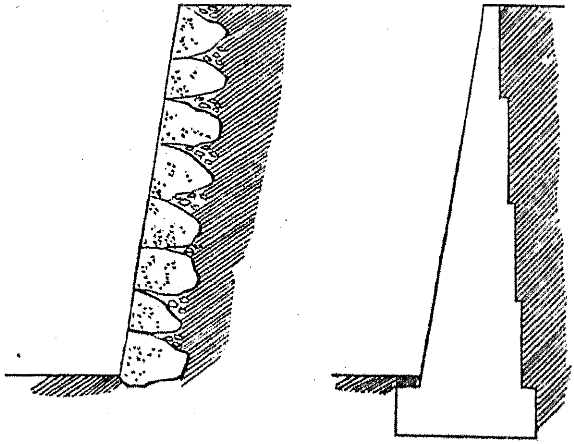


Fig. 9.

had fallen on the inside. This building is roughly speaking of the following dimensions :—Ground storey 108ft. by 120ft. ;

first floor also 108ft. by 90ft.; second floor 80ft. by 72ft.; third floor 66ft. by 54ft.; and the fourth floor 54ft. by 42ft.; the larger dimensions being from N. to S. The total height, including the stone-faced base, is about 160ft. The stone-faced base of this and all Japanese Castle Keeps does not support more than the outer edge of the thick external walls of the structure, these being continued down inside in a series of stepped frames almost to the level of the base of the escarp. This forms a sort of complicated socket arrangement. The building is of decreasing stages, not very high in proportion to their enormous width, so that the complete structure presents an almost pyramidal outline, of no great altitude in proportion to its width of base. It is constructed of enormous timbers, framed and stiffened in every direction, the external walls of the decreasing stages being carried on gigantic beams and lintols, supported on numerous stout posts. The roof is a perfectly stiff heavy framework, and is covered with copper sheeting and heavy gilt finials of metal. The roof was apparently uninjured and even the plaster work of the building seemed not to have suffered. It is reported, however, that closer examination afterwards led to the discovery that this structure had been thrown about a foot out of the perpendicular and extensive repairs were consequently undertaken.

Conclusions drawn by the writer from an examination of the above Castle structures were as follow:—The deep excavated moats of the Castle seemed to have in no way assisted in cutting off the effects of the shock. The comparative immunity of the Keep could not be attributed to them, as many other buildings within the same enclosure had seriously suffered. The made-ground of embankments and mounds had been seriously disturbed and contorted, forcing down the stone facings, which served as a kind of retaining wall. The cracks in level ground were caused by the yielding of lateral support in the made-ground and the effect of settlements, and were not strictly speaking *earth-gapings*. The stone structures were not correctly described as *stone walls;* they had no stability apart from the earthworks they assisted in supporting. They had not even the stability of ordinary European retaining walls built in horizontal beds with mortar, of increasing thickness towards the bottom and with proper footings; such requiring overturning in mass. They were constructed of enormous stones, triangular towards the back, bedding upon one another only a few inches at the joints, the cavities behind being filled with loose gravel. No mortar or bond of any kind was used; see (Fig. 10).



JAPANESE RETAINING WALL. EUROPEAN RETAINING WALL.

Fig. 10.

Nothing but the enormous weight of the individual stones prevented the pushing out of these walls by the mere lateral pressure of the earth, and when to this was added the shaking and kneading of these embankments by the earthquake, they easily collapsed. Similar effects might frequently be seen in stone-faced embankments of less colossal dimensions in which small stones were employed; a continuous fall of rain was often sufficient to cause them to collapse. The Japanese retaining-wall was a sham and unstable *facing*. It seemed important to record such observations, because, in entire ignorance of the conditions, these stone facings had been referred to as examples of *stone walls* which had fallen whilst wooden walls remained standing.

The better built Japanese structures, and especially the turrets and large central Keep, had undoubtedly shown wonderful powers of resistance. To judge intelligently of their height as structures it was necessary to compare it with their extent of base, which was considerable. The Keep was 160 feet high to the apex, but 120 feet broad at the base, gradually decreasing in size and weight towards the top,—in fact a form approaching that of the pyramid. This was undoubtedly a very strong form indeed, if constructed in a material which lent itself to such treatment. It might, on the other hand, be an extremely weak, unstable, and defective form, if constructed in other materials. A building, it must be remembered, was not solid, but consisted chiefly of hollow compartments, and wood lent itself to a method of setting back walls one above the other in decreasing stages. In materials like brick and stone it was imperative that walls should be continuous from below and as equal in height as possible.

The framework of this citadel was enormously strong, and the timbers being of such large scantlings, the ordinary Japanese methods of jointing, which had proved to be so weak and defective in lighter structures during earthquake, did not produce fragility. The great weight added to the stiffness and rigidity of these connections. These considerations tended to controvert the theory that loose and pliable joints in wooden structures, by admitting of an amount of *give*, were favourable in earthquakes; because if this were so, the lighter buildings should have suffered less than the heavy ones in the which joints were more rigid; but the reverse was the case. The great stiffness of the wood framing of this Castle structure was remarkable, timbers and ties running in every direction. Especially was this noticeable in the roof, which was trussed equally in every direction; no trusses could move independently, and the roof structure was compelled to shake in one piece, like a hollow pyramid. The writer considered that in this lay a principle which might be applied to roofs of more scientific construction, when erected in earthquake countries. Another inference from the examination of the Nagoya buildings was, that, whatever conclusions might be reached with regard to brick buildings in general, magazines and fireproof stores, not used as dwellings, and of no great height, were far less liable to injury if built in brick, or even stone, than the ordinary Japanese mud and plaster store-house. The worst that occured to the former was the damage of a few arches to openings, whereas after the earthquake the latter became entirely useless for the fireproof purpose for which they were constructed. Nowhere up to the present had *low* brick structures been found seriously injured.

The buildings of the Nagoya Railway Station were next visited. The Station itself, a temporary wooden building of light framework, with weather-boarding, had fallen. A long Carriage-shed with wooden walls and two rows of posts internally, had bent over considerably. The outer walls were supported upon a stone plinth, but the inner posts were let into the ground, framed into cross plates with struts. These had tilted up through the soil, forcing up the earth, and the whole structure was leaning West (see Fig. 11). The roof trusses, though simple in construction, had longitudinal plates between them which were strutted, giving longitudinal stiffness not present in the ordinary European house-roof, where trusses were only tied by purlins. This roof was uninjured, having apparently moved in one piece.

A large iron water tank of cylindrical form, 14ft. in diameter and 7 feet deep, holding about 7,000 gallons, and supported by girders placed on a ring of cast iron columns standing on a brick and stone base, had been shifted on its supports about

6 inches East. The tank is said to have been full of water at the time of the earthquake. A similarly constructed one at Ogaki Station was reported to have been thrown down and broken to pieces.

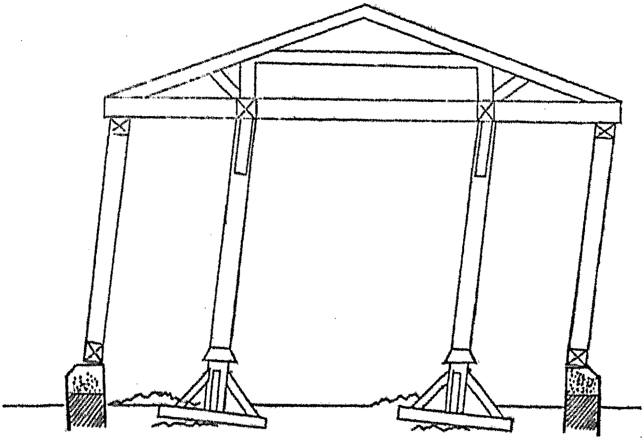


Fig. 11.

The next building examined was a large brick Engine-shed 200 feet long, 45 feet in span, and with walls two bricks thick and about 18 feet high. It was covered by a flattish queen-post roof and had a wooden lantern and end gables of brick. The large arches of the triple entrance were constructed in three half-brick rings with key-stones and abutment stones. There were cracks over the arches, and the key-stones had opened, one falling out. In one case a brick arch had slipped bodily at its junction with the stone abutment. There were also large cracks at the corners of the gable ends running from the projecting wall plates diagonally downwards through the corner arches; these were in some places as much as two inches open (see Fig. 12). In the case of one arch in which the key-stone was intact the lower ring of bricks had loosened and dropped back (see Fig. 12). The movement of the wooden roof had much disturbed the tops of the walls. The brick beam-filling between the tie-beams, above the wall plate and behind a continuous outer roof plate, had been loosened and pushed in by the vibration of the roof (see Fig. 12).

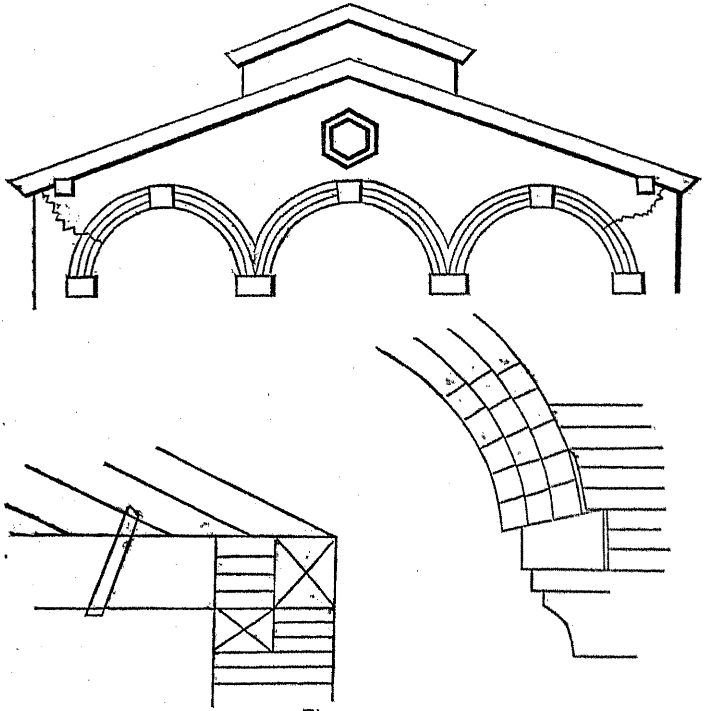


Fig. 12.

A low brick annex of thinner walls and with a lean-to roof attached to the Engine-shed, had suffered considerably, its side walls being pushed and made to bulge out by the movement of the main wall of the shed, and the window openings were much crushed and injured : one of the cross walls was cracked from top to bottom near its connection with the shed wall, as if torn apart. Several courses of bricks in the main shed were pushed out below the trusses, revealing their white mortar-covered under surfaces. The mortar seemed to be tolerably adhesive.

Conclusions drawn from the examination of the above structures were:—That light fragile buildings like the temporary Station offered no powers of resistance. It seemed also questionable whether the internal posts of the leaning wooden shed above referred to had been an advantage or otherwise from a seismological point of view. They may be considered to have somewhat stiffened the structure and prevented its complete collapse, at the same time they apparently acted like large inverted pendula assisting the structure to swing over and dragging its walls off their stone base. The longitudinal strutted truss to the roof had, it appeared, kept it stiff and complete. The condition of the brick buildings confirmed the impression that structures of this material with walls of sufficient thickness and no great height,—even with no cross walls,—were not likely to be overthrown, but cracks would occur over arches and at other weak points. The damage invariably caused to the tops of brick walls by the loose timbers of the roof was confirmed. The Engine-shed showed the first example as yet observed of damage done to an annex of smaller size and lighter construction connected with the main structure, and was probably accounted for by the different masses, weights, and consequent different periods of oscillation of the two portions.

The Nagoya Cotton Mill, next inspected, was a combined wood and brick building. The first Cotton-spinning Hall was a one story wooden building about 16 feet high, and 170 feet long by 72 feet wide, covered in two 36 feet spans of queen-post roof, and containing three rows of wooden pillars one under the centre of each truss and one under the central valley. At the end of the hall was a brick Engine-room, the end wall of the hall being of brick, two bricks in thickness. In the wooden hall there was no damage except that the glass of the windows had been smashed by the shock. Against the brick wall the roof timbers had been carried on brick corbelling, and this corbelling had been dragged and broken by the vibration of the roof (see

Fig. 13). The tops of the doorways in this and other brick walls had no relieving arches but were carried on thick wooden lintols, and these lintols had moved, some being drawn partly out, the brickwork between their ends being battered and cracked (see Fig 13).

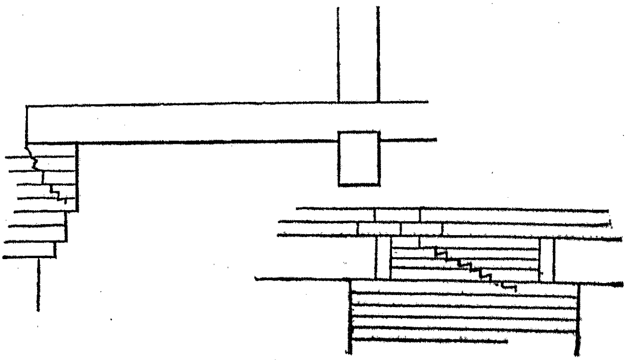


Fig. 13.

A sort of buttress wall inside the Engine Room, at right angles to the brick divisional wall between Engine Room and Spinning Hall and partly corbelled out from below, was damaged, a portion of the centre being detached and partly thrown out (see Fig. 14). This wall was reported to have been cracked previously, owing to a sinking occasioned by defective foundations. The mortar was found to be poor in quality. The adjacent brick chimney had fallen, damaging a portion of the roof of the Engine Room.

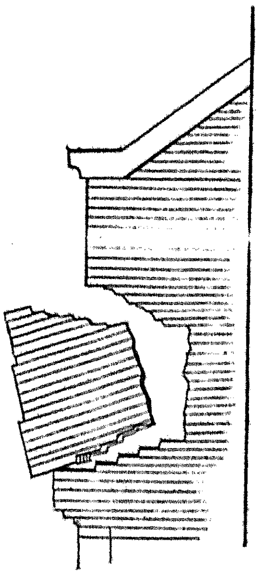


Fig. 14.

Another large wooden Spinning Hall (see Fig. 15), 180 feet by 108 feet, with roof divided into six 18 feet zigzag spans zinc-covered on the broad slopes and glazed on the steeps, and supported by 5 internal rows of wooden pillars, was not injured, though the shaking is reported to have been so intense that the machinery violently vibrated. The machinery in the hall showed signs of having been twisted in a Northerly direction. This building was lightly

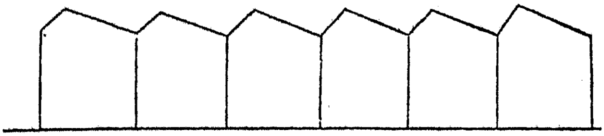


Fig. 15.

constructed with thin posts, covered on the outside with Japanese weather-boarding, with low walls and a light roof divided into may spans. In another part of the compound a portion of a large low wooden building having thin uprights and a heavy king-post roof had completely fallen, East by North, being torn away from the rest of the structure (see Fig. 16).

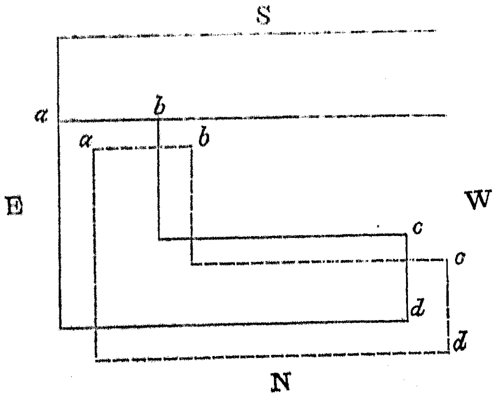


Fig. 16.

The top portion of a large octagonal brick chimney 14 feet wide at the base and originally 85 feet high had fallen from a height of 35 feet. The greatest thickness of the brickwork was three bricks and a half, at the point broken off it was two bricks and a half, and at the top one brick and a half. The pedestal portion below had been constructed in cement mortar, and the upper part—where broken—with common lime mortar. The remaining portion of the chimney above the pedestal was much bent and cracked (see Fig. 17). Bricks manufactured by the Toyokumi were used, and this chimney was constructed about $3\frac{1}{2}$ years previously by an Engineer from the Ishikawa-jima Zosenjo, Tokio. Close by was another smaller round chimney 8 feet in diameter at the base, originally 55 feet high, 6 feet in diameter above, and of this about 30 feet had fallen, the part remaining being severely cracked right down to the base. The bottom was two bricks and a half thick and the top only one brick thick, and it had been constructed 8 years ago of the first bricks made by the Toyokumi in Nagoya. No cement mortar was used, even in the base, common lime mortar being employed throughout.

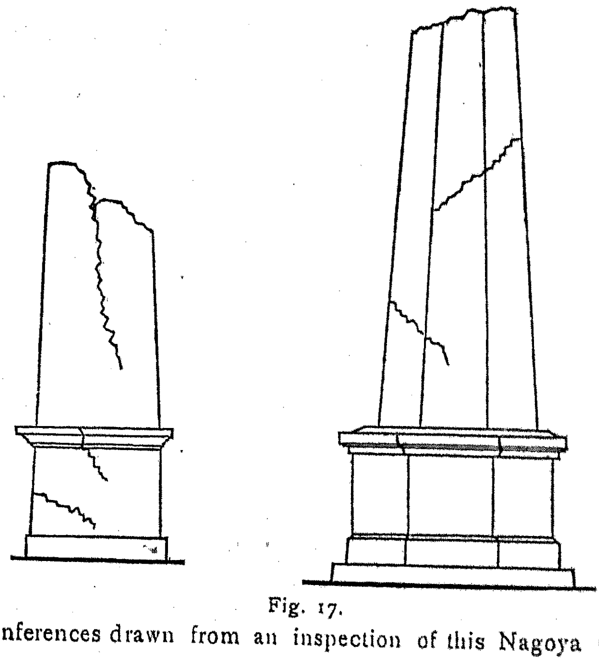


Fig. 17.

Inferences drawn from an inspection of this Nagoya Cotton Mill were :—That low one-story wooden buildings like these Spinning Halls, of great extent of base in proportion to their height, and of simple square plan, though receiving severe shaking, did not collapse, although the machinery was much damaged and the glass of windows broken by the excessive oscillation and yielding. Also, a light roof divided into many spans, covered with metal and approaching a flat form, and supported internally at numerous points, showed a possible advantage. On the other hand, a light wooden building of comparatively narrow base and quadrangular plan was torn off at one angle and had completely collapsed. Undoubtedly, age, weakness of joints, and other defective construction, partly accounted for this, but the proportion of width to height, and particularly the complication of plan may have assisted. Whereas a building of one simple mass would swing in one piece, the parts of a structure having different attachments would tend to oscillate independently, resulting in the tearing off or shoving over of outer portions in the direction of the greatest movement.

The brick portions of these buildings, confirmed former experiences of the damage done to the tops of walls by roof timbers resting on them and not anchored in any way. The weakness of brick corbelling subject to such strain was plainly shown. The shoving and battering action of wooden lintols let into brick walls over openings was instructive, and partly explained the effects seen over door-ways in plastered brick walls in the Shirei Hombu (see Fig. 4, page 8). The damage to the brick buttress-pier in the Engine Room showed, —firstly, the damage done by earthquake to parts of brick buildings where small settlements and cracks had commenced owing to defective foundations; secondly, the danger of top-heavy or corbelled construction; and lastly, tended to confirm the remarks already made as to light attachments to heavier masses. The example was a parallel one to that of the Locomotive Engine-shed in the Nagoya Railway Station.

The damaged chimneys confirmed the observations noted regarding other high brick chimneys, and at the same time showed the superior advantages derived from thicker brickwork, harder bricks, and particularly from the use of cement mortar.

The Owari Cotton Mill was next examined. This was the brick building which had received the greatest damage from the earthquake and had occasioned the largest loss of life and injury to the inmates. It was built by the Nagoya Kenchiku Kaisha, the builders of the Post and Telegraph Offices, from the designs of a Cotton Mill engineer. It consisted of a large two story oblong Spinning Hall about 282 ft. long by 102 ft. in span, having a total height to the cornice of about 40 ft., except in the water tank tower, which was about 14 feet higher. The walls of the Spinning Hall were 2½ bricks thick below and 2 bricks thick above, and there were no internal cross walls. The upper floor, which supported very heavy spinning machinery, was of wood, beams being let into the brick outer walls and supported by rows of cast iron columns internally. The walls had large window openings, about 8 feet wide, 12 feet high, and 6 feet apart, the openings on the upper story nearly equalling in combined area the remaining area of the wall surfaces. The windows were arched with flat segmental arches. The tank tower was of the same thickness on the ground and first floors as the rest of the building, but piers of half brick extra projection were built at the corners. The upper story enclosing the tank had walls one brick thick and one brick and a half thick at the corners. The tank was of wood, supported on a large brick pier carried up in the centre of the tower. The upper wall of this building had completely fallen on the West side and South end from the level of the upper floor, and on the East side from the level of the cills of the upper windows. The top story of the tank-tower and part of the next story had fallen, exposing the wooden tank; the remaining brickwork of the next story was much cracked. An examination of the brickwork showed that the mortar was rather crumbly, though tolerably adhesive to the bricks in parts. But in other parts the bricks appeared quite clean, not even stained by mortar ; especially was this the case in the vertical joints. The whole of the upper floor, with the heavy machinery it carried, had fallen in, the cast iron columns had been broken, twisted, and thrown over, and the sloping tile-covered roof had fallen with the collapse of the upper walls. A large brick chimney, originally about 120 ft. high, had half fallen.

Considerations based on this examination were as follow :—Bearing in mind the enormous size of this building, having no cross walls, an upper floor loaded with machinery of enormous weight, and a heavy roof, the brick walls were of minimum thickness for safety and had no projecting piers. Added to this was the fact that the amount of window opening was almost equal to the solid surface and the widths of such openings were one third greater than the width of dividing piers. The upper floor had not assisted in tying in the walls, the beams being only let loosely into the brickwork. The intermediate cast iron columns had carried much of the weight of the floor and roof, but they had swung like pendula, together with the upper floor, assisting in pushing out the walls and drawing the beams from the walls. The tank-tower had enclosing walls of much less diameter than the Spinning Hall and its first story remained standing, but the top story had fallen. This might have happened under any circumstances, as this upper wall was only one brick thick, but the form of the fracture and the method of carrying the tank on a central pier suggested the conclusion that it had been battered out by the swinging of the tank on its central pendulum.

The Atsuta Cement works were visited for the purpose of seeing further effects on brick chimneys. The kilns and chimneys of this establishment were constructed by the local bricklayer, Hasegawa. Common lime mortar was used, but it was not very adhesive, the sand appearing bad. The tops of the kiln chimneys were all broken off. There was a large square brick chimney, originally about 78ft. high, of which about 25ft. had fallen, partly E. and partly W. In the remaining portion the brick joints had been loosened in many places and a twisting had taken place from E. to W. by S. causing curious effects at the angles creating an indented appearance when viewed diagonally, as sketched in Fig. 18.

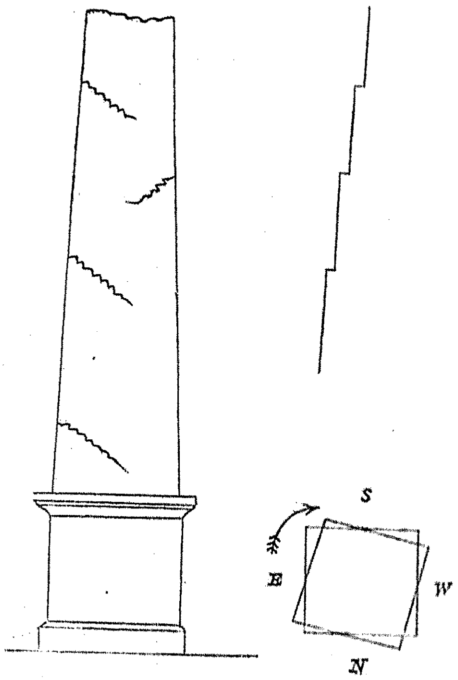


Fig. 18.

Among the street houses of Nagoya was a so-called brick building, which had received serious damage. This was called the *Aichi Kankoba*,—a kind of Bazaar. An inspection showed that it had only one brick façade and short wings carried about 15ft. back, the rest of the structure being of wood and plaster. It was of two low stories ; the lower walls of the façade being 1½ brick and the upper walls 1 brick thick. The lower part of the façade had two wide arches with a central granite pier and side pilasters of granite let into the brickwork. Above had been two windows. The top story had fallen to the level of the window sills. An examination of the mortar showed it to be have been almost useless. The stone jambs of the archways

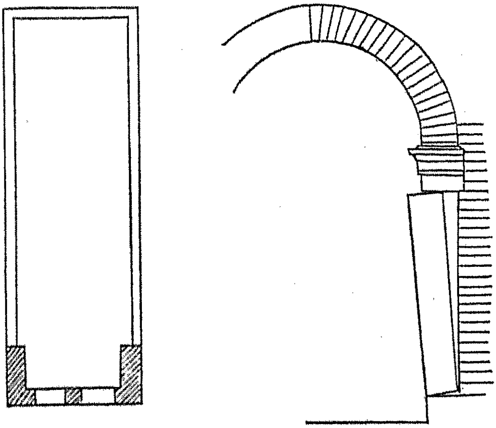


Fig. 19.

had been thrown out, one remaining caught under the cap as in Fig. 19. It seemed unnecessary to dwell on the defects of this building which was of the falsest and worst construction; a typhoon alone would have probably been sufficient to destroy it. The brick portions of the structure were weak, unstable, and badly built with useless mortar, and they only had three sides to stand upon. The swinging of the wooden protions behind had probably assisted in pushing over the upper walls. The projected stoned jambs afforded another example of the pushing or shaking out of stone not bonded, cemented, or cramped to the brickwork, and especially of long blocks having little penetration in proportion to their height.

A cursory inspection was made of the following buildings. The Nagoya Eiwa Gakko, a high wooden building in foreign style, had clap-boarded walls, and a high pitch tiled roof with dormer windows. No great injury was observable from the outside, but the brick chimneys above the roof had all fallen, and the roof tiles were loosened. A small house close by had low brick chimneys remaining, only the tops being broken off.

The Nagoya Shihan Gakko, opposite to the above, was also a wooden building of two stories in foreign style, with walls plastered and instead of being clap-boarded. The plastering was executed in Japanese style, clay being used below and with an upper coating of lime plaster. A great portion of this plastering was thrown off and the wooden posts and beams below were exposed. The brick chimneys above the roof had fallen and the tiles were loosened. The Kencho Gijido (Prefectural Assembly)—a large wooden building, comparatively new, in foreign clap-boarded style, and with a large roof, had some of the roof tiles thrown off, but other parts were apparently intact. The Christian Church a high clap-boarded building with wooden tower and spire and metal roof showed from the outside no signs of injury.

The condition of the above wooden buildings of foreign style seemed to show that clap-boarded structures resisted better than plastered wooden ones. The advantage of protection from fire afforded by the plaster was lost after earthquake, as the wood became exposed. Metal covered roofs had fared better than those tile-covered. The brick chimney-stacks above the roof lines had proved in all cases dangerous. The condition of these buildings confirmed the public report that wooden buildings of foreign design (*Mokuzo seiyō dzukuri*) had made the best record in the earthquake, next to the Japanese Castles and other very heavy and superior Japanese buildings.

The writer devoted a day to the closer examination of city buildings, and other structure of pure Japanese style. The Shukinro, a first class Japanese hotel, was seriously damaged, but it appeared that the portions most injured were crushed in owing to the fall of the upper walls of the adjoining Post and Telegraph Office. A large two story annex of this hotel, consisting of a number of tea rooms and small chambers below with a large 120 mat room above, had at its West end a heavy Japanese Store, close to the Eastern end of the Post and Telegraph Office. The falling brickwork had knocked over this heavy Store crushing in the top portion of the hotel annex. The lower story posts and parts of the lower ceilings remained standing, and a portion of the East end remained complete *in situ*. Those parts of the hotel which had not been damaged by adjacent objects showed signs of terrible shaking in large cracks and rents, horizontal and vertical, in the plastered (*kabe*) panels of the rooms, and the edges of these plastered panels were separated from the posts, but the posts and beams remained intact, as well as the wooden ceilings (see Fig. 20).

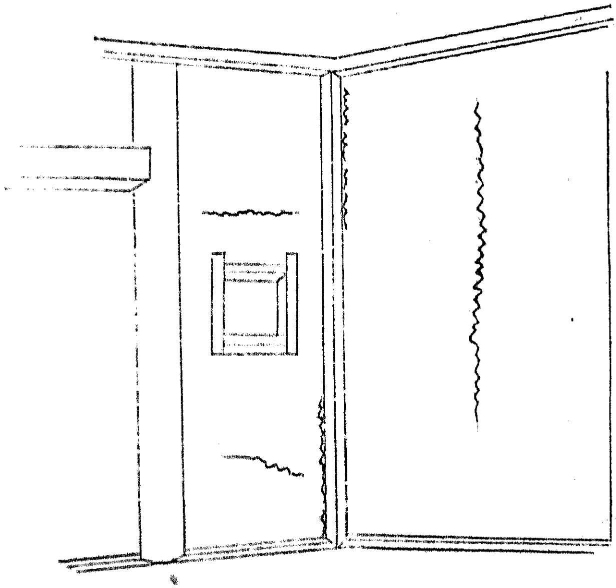


Fig. 20.

The gateway entrance of this Japanese hotel was in foreign style, and the tops of the stone pillars presented an interesting example of rotation during the earthquake, the glass lamp box above serving as a guide to the direction the rotation had taken (see Fig. 21). The tops of some stone lanterns in the inner garden were thrown over. Round the front garden was a high wood-and-plaster fence with projecting roof of boarding, and part of this roof had been thrown off.

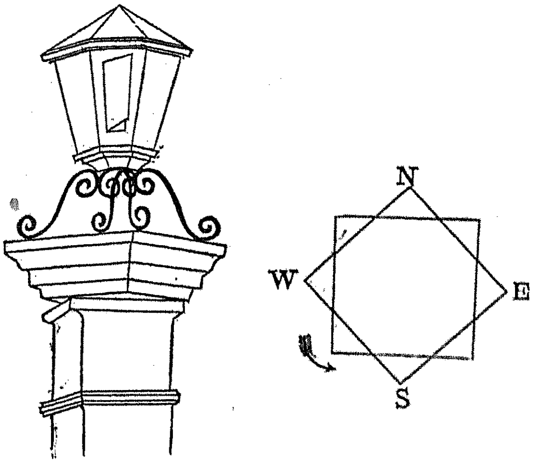


Fig. 21.

The Hongwanji Temple, one of the finest and most solid of the temple buildings of Nagoya, was next visited. The magnificent Sam-mon, or two storied entrance gateway, of heavy construction, was intact, as well as the main Temple Hall or Hondo. This latter structure had colossal timbers, the posts, being 18 inches in diameter and some of the beams and cross ties 3ft. deep. Even the heavy ridge tiles and terra cotta terminals of the roof seemed unchanged. In the connecting passage of lighter construction adjoining the Temple a few plaster panels had been shot out bodily and others were severely cracked. The detached outbuildings were somewhat damaged in their roofs, the tiles being thrown off. The end of the ridge of a porch to one of these buildings was shoved out. In some of the secondary gateways, having thatched roofs with tile ridges, the terminals of the tile ridges had fallen and the ends of such roofs were bent over. On the other hand, the ends of the curved lean-to roof extending over the porch of the Hondo had large terra cotta terminals of high rearing lions steadied only by thin wires, and these were not injured, showing that the roof had moved in one block, see Fig. 22.

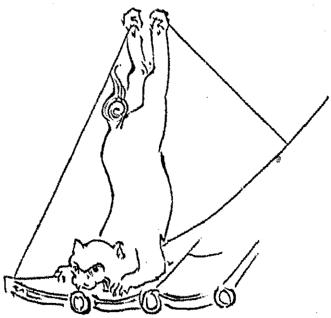


Fig. 22.

A heavy bronze bell suspended in a beautifully framed and carved bell-shed, raised on a high stone-faced base, had fallen, but the bell-shed itself was not injured. A common and some-

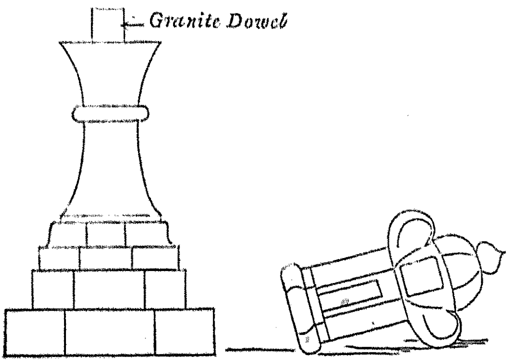


Fig. 23.

what lightly constructed Japanese building near this had fallen in, and a *nagaya* on one side of the court had its plaster thrown off. The top of a bronze lantern had fallen, showing the existence of a large square granite dowel inside the bollow bronze drum, fixed tightly with pebbles below but apparently only loosely penetrating the cap, which had been shot off, see Fig. 22.

The next temple visited was the Wakamiya, the grounds of which are now a public park. Here several large stone lanterns

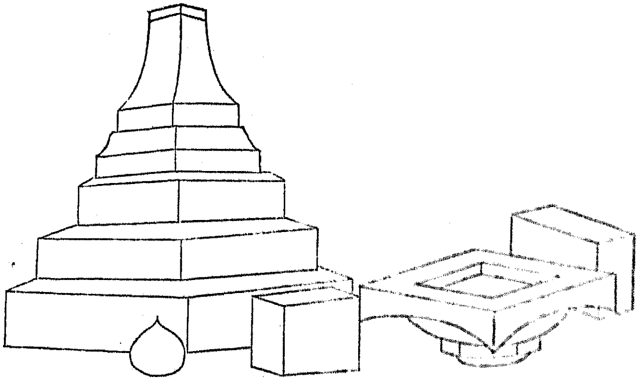


Fig. 24.

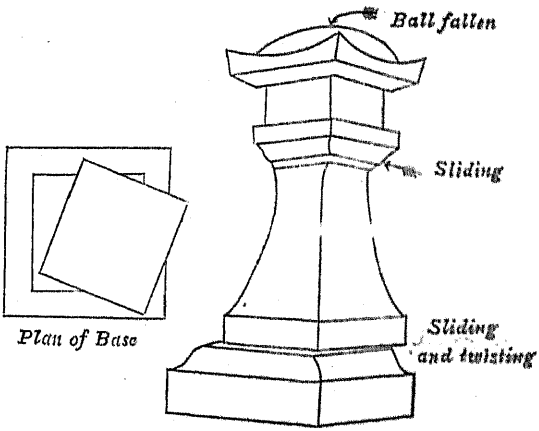


Fig. 25.

which had moved and fallen were examined and sketched. The top of a large stone lantern, Fig. 24, had been thrown over in a South direction. Another had remained standing but had been moved and twisted at the joints (see Fig. 25). The plan shows the sliding movement at the base in a South direction, with a twist toward the West. The cap had also slid about 1 inch East; and the top ball had fallen and rolled to a considerable distance South. The above lanterns were of no very great size. Another colossal stone lantern about 16ft. high had fallen to pieces, spreading out in a direction S.W. by W. (see Fig. 26).

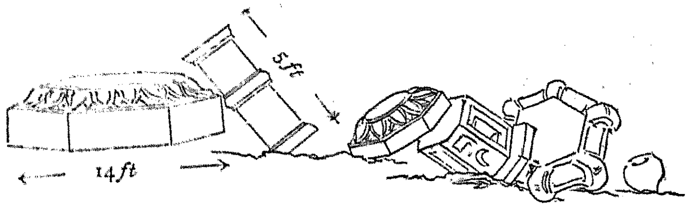


Fig. 26.

The separate stones showed no dowels, dowel holes, or connections of any kind. Opposite the dancing stage (*Kagura-do*) of the same temple two similar stone lanterns had fallen in exactly opposite directions (see Fig. 27). Numerous other small lanterns had been thrown down.

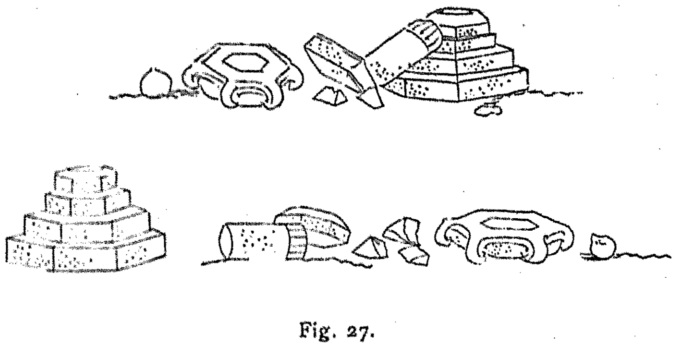


Fig. 27.

The next visit was paid to a famous temple called Kenchiuji, containing the mausolea of the Bishiu branch of the Tokugawa family. With the exception of small repairs the buildings were 200 years old. The outer gateway, a heavy structure, was standing intact except that the posts had slid slightly E. on their stone bases. The *Hondo* or main temple had some tiles fallen, and the walls were cracked at the junction of connecting passages, the plaster panels having been loosened and separated from the mud backing, in thin sheets. Also the plastering (*kabe*) inside was much damaged. A detached double story building, strongly constructed, had large panels of plaster fallen off. Every one of the numerous stone lanterns on the sides of the paved approach had fallen in pieces in different directions making a heap of *débris*. In the large cemetery yard behind about 200 stone lanterns had fallen to pieces apparently in no fixed direction.

This was in front of the fifteen enclosed tomb-courts containing the remains of the Bishiu Tokugawas from the 2nd to the 16th, inclusive. The stone railings round these burial enclosures, which were of stone posts and rails tenoned together like wood construction, had fallen to pieces in various directions, but mostly N. and S. Most of the wooden entrance gates of these courts, which had heavy roofs, two supporting posts, and buttresses on one side, had fallen forward on the side having no buttresses. The construction of these buttress posts was peculiar. They consisted of wooden pillars tenoned above into the cross beam of the roof and scarved and strapped below to a granite end let into the ground (see Fig. 28). In

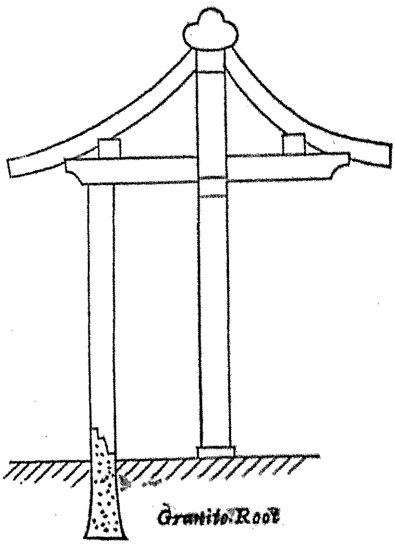


Fig. 28.

some cases of overthrow the scarf joint had given, in others the granite root had been drawn out from the earth. Some gateways had the posts merely loosened, but the handsomely carved wooden doors thrown out of their sockets and the panels smashed. Some of the stone cenotaphs, of flattish form curved at the top, had been thrown over in a S. direction (see Fig. 29.); but their form was unfavourable to overthrow in any direction but S. or N. The local priest reported that, generally speaking, those railings and buildings which faced E. had been most badly injured.

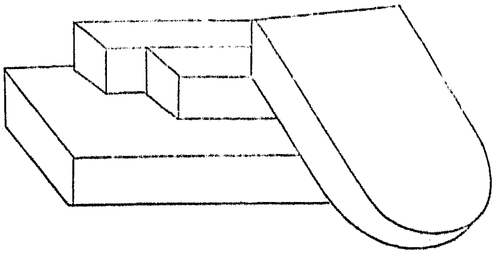


Fig. 29.

Another temple called the Shrine of the Gohiaku Rakkan had its outer fence much broken. A bell-shed containing a medium sized bronze bell showed that the four posts had slid on their stone bases 1 inch West, but the bell was still hanging. All the buildings of this temple, including the Hondo, were plastered, and the plaster was much cracked and had fallen off in masses. Inside, the plaster was torn and broken, being separated from its clay backing. The posts and roof of the Hondo were apparently intact.

At the Tokugen Temple, Nagoya, part of the tile ridge of the Hondo had fallen off.

The Prison at Nagoya was next visited, many casualties having occurred there. This consisted of solid but old Japanese buildings converted from former military rice stores. Their construction was heavy, the posts being of considerable thickness, but the joints loose and partly decayed. A large building used by the prisoners for grinding rice in was leaning over bodily in a W. direction at an angle of about 60 degrees, the posts having their dowels drawn out of or broken into the ground cills and the intermediate plaster-work broken and fallen (see Fig. 30).

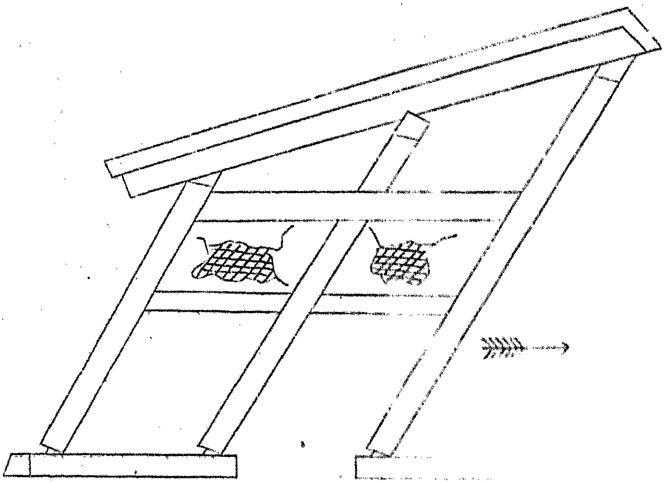


Fig 30.

There had been two heavily constructed shed buildings one on either side of a pathway 20 feet wide, and these had both fallen. Eye witnesses declared that these two buildings swung so during the earthquake that their eaves almost met, eventually one falling E. and one W. Other sheds had fallen killing three and injuring thirty prisoners engaged in making matches. There was an example of a shed building leaning longitudinally South.

The Chitose Theatre, Nagoya, was next inspected. Though a Japanese building, the roof was a modern one of light king-post construction, covered with metal with a large central lantern box for lighting; and half of this roof over the pit had collapsed; a part of the roof over the stage had also broken in.

Another Japanese theatre called the Shimmori had entirely collapsed and the surrounding electric lighting poles had been pulled over.

An excursion through the suburbs of Nagoya and the neighbouring villages on the road to Gifu was the occasion of an examination of the more ordinary Japanese buildings. In the suburb of Higashi Biwajima, long rows of street houses were leaning longitudinally in a Western direction (not over the street as at Atsuta.) Further on there was a large area occupied by houses which had completely collapsed, the tiled roofs having flattened out on the top of the fallen posts, beams, &c. The long wooden bridge of the Biwajima river was broken and waved in the centre with a large swoop towards the S. E. The stout wooden piles about 15 inches in diameter, supporting it from the bed of the river, had some of them sunk down, some broken in the middle, and some torn away at the scarved and bolted joints (see top of Fig. 31).

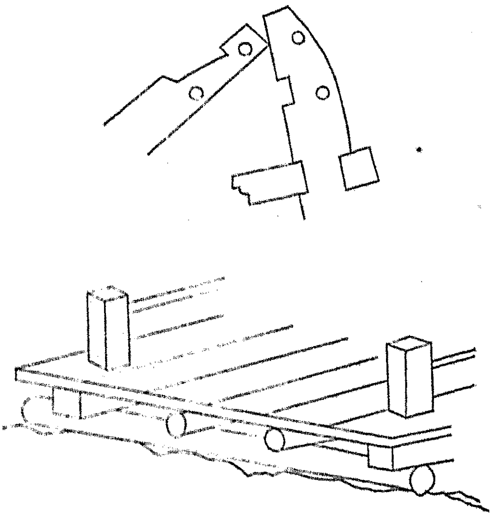


Fig. 31.

The Japanese fire-proof stores were all leaning distorted and had their thick clay and plaster coatings thrown off. At Nishi

Biwajima the street houses were of poorer construction, having thatched roofs, and these without exception had all collapsed, but the roofs had fallen bodily, making triangular huts in which the inhabitants sought refuge during the night. The blackened timbers and plaster suggested fire, but this proved to be a sign of age and owing to the use of open wood fires internally for kitchens with no chimnies. At Tataki village, a little beyond Nishi Biwajima, the road becomes a raised causeway (*doté*) of made ground; and this had spread, sunk and cracked in many places, leaving the small wooden bridges (which were supported partly on piles driven into the hard bed of the crossing streams), raised above the road levels at their ends (see Fig. 31).

At Ichi no Miya, a small town next reached, about one half of the houses had fallen, the rest being shattered and bent over. In some cases parts only of houses had fallen, being torn off from the remainder. Of the leaning houses, some leant N. and some S. In the streets of this town the same phenomenon had occurred as already mentioned in alluding to the Nagoya Castle on page 12. White liquid clay and sand known to exist at considerable depth below the surface had been squeezed up, spirting above the ground. The principal temple of this town, called Masumida Jinshu, was examined. The large two-story gateway was standing apparently uninjured, but on closer inspection it was found that the heavy supporting posts had been shifted, some 5 inches, and one as much as 8 inches in a N.E. direction. Two large open Prayer Sheds (*Hai ya*), with large round pillars, were leaning and twisted in an Easterly direction, one pillar having slid 5 inches East.

The top of a large stone lantern had fallen, and the body had twisted on its base from E. to W. by S. (see Fig. 32).

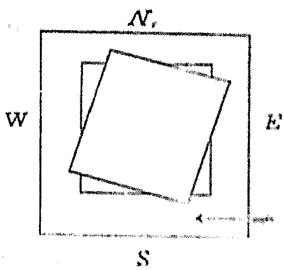


Fig. 32.

Near the same spot the top of a bronze lantern had fallen, showing a large granite dowel let inside the hollow bronze standard and kept in position by gravel and stones. Some stone lions (*shishi*) had slid on their pedestals.

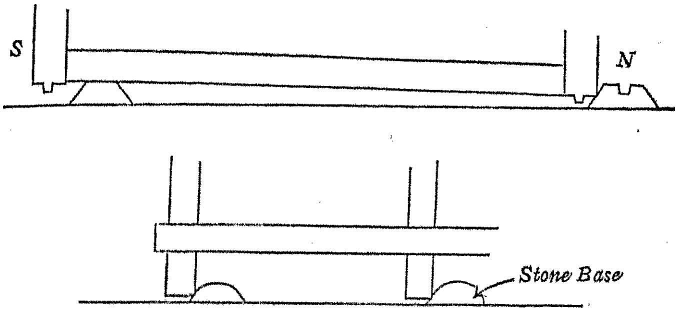


Fig. 33.

A curious case of lifting and sliding was shown in a closed well shed, the pillars having been lifted off the stone bases although dowelled into them (see Fig. 33). The dowels remained unbroken. In another instance the posts of a Prayer Shed had been slid off the rounded stones which carried them (see Fig. 33).

An interesting example was here observed of a copper eaves

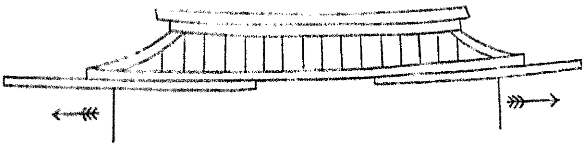


Fig. 34.

gutter, loosely supported on hooks and jointed in sections, being detached in the middle and shaken out in opposite directions (see Fig. 34).

Many conclusions were gathered from the inspection of the above Japanese structures of various kinds in and around the city of Nagoya. It seemed an indisputable fact that the monumental class of wooden buildings of pure Japanese construction showed remarkable powers of resistance to the earthquake. Such damage as had occurred to them was the falling of plaster-work and tiles, and in some cases a sliding and twisting of the supporting pillars which had in two or three examples shifted the structure off the isolated stone supports, but without throwing it perceptibly out of the perpendicular. Lighter buildings annexed to these heavy structures had invariably been damaged by the oscillation of the heavier mass. The roofs in all cases showed wonderful stiffness, and in many instances not a tile was shaken off. Tiles where used in combination with thatch had been thrown off. On the other hand, the ordinary Japanese city buildings, and a few of the older structures of better class, had yielded like a broken chair, collapsing when not held up by adjoining structures. The same principles and methods of construction were followed in these ordinary buildings as in the large temples; the weight, size of timbers, and consequent strength and stiffness of joints in the latter alone distinguishing them. It appeared to the writer therefore that the advantage was not one of method of construction, but rather one of strength and mass in the heavier structures. The scantlings and mass employed in these monumental structures it was impossible to apply to ordinary structures, both for reasons of utility and economy. Also it must be remembered in comparing them with other classes of buildings that there existed no monumentally solid structures in masonry or brickwork to compare with these temples, such brick buildings as had been examined being mostly of the speculative or commercial class and of poor construction.

To arrive at exact conclusions as to uniformity of direction in which structures had been most damaged or overthrown it would be necessary to compare notes taken of fallen objects in different localities with the direction of the earthquake centre. Possibly some degree of prevailing uniformity would be found to exist. The street houses in Biwajima had, for example, all lent longitudinally West in the direction of Gifu, though they laterally supported each other in this direction, and it would consequently have been easier for them to lean over the street as was the case near Atsuta. Also the priest's observation at the temple of Kenchiuji was that gateway structures which faced E. and W. had been most thrown over. But, on the other hand, temple buildings square in plan had been shifted South, and stone monuments of regular plan had been thrown over in all directions. In some cases, as with the stone tablets of mausolea, the direction of fall was evidently governed by the shape of the object, which from its nature could hardly have fallen edgeways. The observations of the damage to the raised roads and to small bridges upon them confirmed previous opinions expressed as to the dangerous instability of made-ground during earthquake, and especially of embankments of made-ground unsupported laterally. Most of the so-called cracks, openings, and subsidences in the earth during earthquake were really the breaking up of artificial heaps and mounds of comparatively loose soil, and such effects seldom occurred in the hard, level, and natural soil. The bed of the Biwajima river appeared to have been subject to a violent and permanent movement of its bed.

Proceeding towards Gifu the banks of the river Kiso were soon reached. These artificial embankments about 40 feet wide, to keep out the floods, are constructed for the most part of fine river sand with a top surface of hardened clay about 6 inches thick. These banks had been flattened out by the earthquake, sinking in large waves, producing enormous cracks and fractures, and in some cases changes of level of from 2 to 3 feet. In parts, great hollows had been formed in the centre, the sides remaining at almost their original level. The railway bridge over the Kisogawa was casually inspected. The main bridge supports were oblong tapering piers of brickwork, arched at the bottom, and these arches all appeared to be injured. The end brick abutment was cracked considerably. The river was a double stream, and a sand causeway between the bridge over the main stream and the secondary bridge over the tributary, had sunk several feet. One of the large brick piers of the tributary bridge, having granite quoins, had slid on its base of brickwork in an Easterly direction. The end piers supporting the main girders had separated from their wings which supported the ends of the earthworks (see Fig. 35).

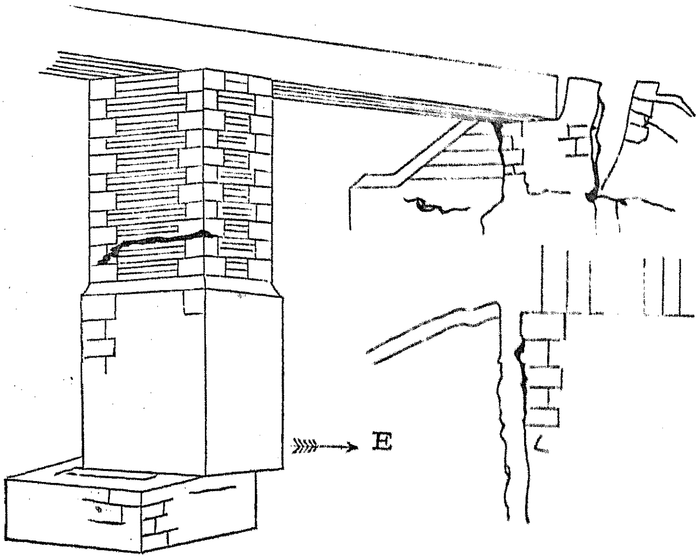


Fig. 35.

What had once been the pretty little town of Kasamatsu was next reached. This town before the opening of the railway had been an important stopping place on the road from Nagoya, being close to the old ferry across the river, having some very fine hotels and well built houses. It was now completely destroyed by conflagrations which broke out after the earthquake. It was said that eleven fires had burst out simultaneously, and so complete was the destruction that not even a godown remained, the whole being a heap of plaster, mud, tiles, and charred timbers. This afforded one of the most calamitous examples of the destructive effect of fire after earthquake in wooden cities, and of the uselessness of the Japanese fireproof store as a protection against fire in such cases.

The village of Kano was next visited. Here there had been no fire, but the majority of the houses had fallen in, a few

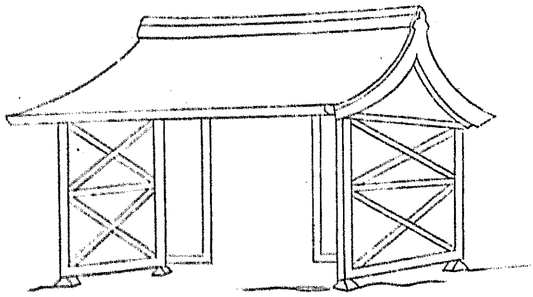


Fig. 36.

isolated ones remaining standing, but very much distorted. An interesting example was here observed of a light Japanese gateway having its side pillars tied by diagonals; this had fallen over bodily, the framework being uninjured (see Fig. 36). The diagonals appeared to have prevented any movement in the joints of the framework, and, instead of the posts giving at the connections and the roof falling, the whole had been tipped over in a mass. This could hardly have happened if the structure had in some way been fixed to the ground at its base. The loose isolated supports of a Japanese building here showed a decided disadvantage.

On visiting the town of Gifu it was found that one portion of the city had suffered much more severely than another. The division was marked by a sunk rent running diagonally through the town and perceptible even across the hard roads. On the side of this rent included in the N.E., N.W., and S.W. quarters, the effects were most severe. Considerable portions within this area had been destroyed by fire, presenting the appearance of a large plain of smoking *débris*, only a few go-downs remaining, and these were scorched and half deprived of their fireproof coverings. It was stated that about 75,900 *tsubo* of buildings had been burnt, covering an area of 158,000 *tsubo*, or 129 acres. Other ordinary Japanese buildings which were not burnt were much bent and distorted.

Gifu only contained one brick building, and this was in course of construction, namely, the Go Rio Kioku or Office of the Forestry Bureau of the Household Department. The brick walls had been carried up nearly to the roof level, but were new, the mortar not having properly hardened. The roof had not been put on. The top portion of this incompleted structure was shaken down and presented the appearance of a ruin.

The Shihan Gakko, a semi-foreign wooden building of two stories, was much cracked but still standing erect. A common shed-like dining hall, in the yard behind the main school, had fallen. A separate wooden building about 35ft. by 50ft., used as a Gymnasium, of one story but 16ft. high to the beams, was intact. It had an open roof, which showed an arrangement of queen and princess roof-trusses of light timbers but stiffly strutted and also trussed longitudinally between the princesses. The posts of the wooden walls were also well strutted with diagonals. This building exhibited scarcely any signs of shaking, the roof (see top of Fig. 37) showing no contortion or signs of movement whatever. Other roofs of much stronger build had been seriously twisted and injured, especially those of so-called European construction. The ordinary European roof consisted of trusses scientifically framed with struts and braces, which were placed at distances of from 8 to 12ft. apart and tied longitudinally only by the purlins, ridge pieces, and pole plates, which were merely notched on to the principals; thus, though the trusses in themselves were stiff, the roof had no stiffness longitudinally, and the trusses could work independently during a violent upheaval and shaking. Many cases of broken wavy roofs showed that this had happened (see middle of Fig. 37). Here, on the contrary, was a roof which was trussed in both directions, and it had apparently vibrated in one mass. This was exactly the same principle of construction as was carried out, though in a less scientific manner, in the large temple roofs and other well built Japanese roofs which had given such good records. As already pointed out, these roofs were as stiff in one direction as another, tie beams and collar pieces being carried both cross-ways and longitudinally. In the poorer and lighter Japanese structures, though the same principle was followed, the smaller scantlings of the timbers, weakened at the joints by much cutting, and having no

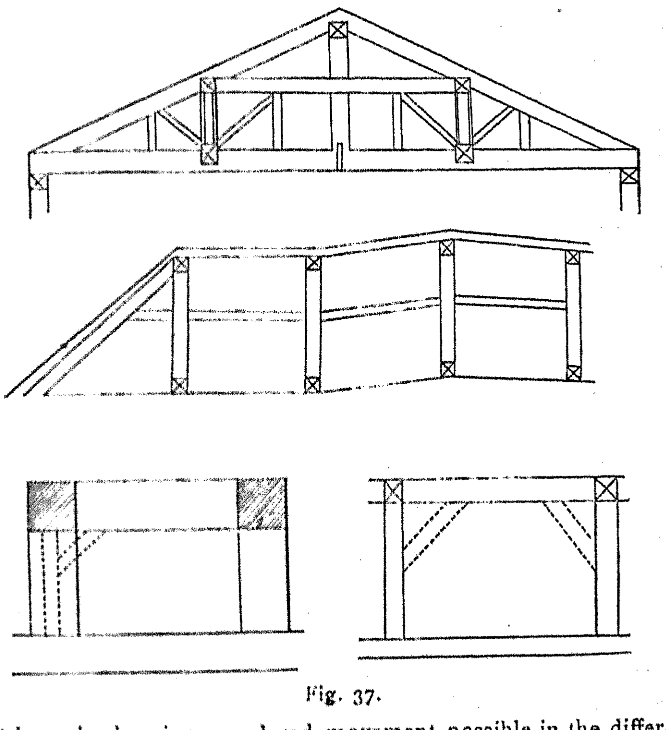


Fig. 37.

triangular bracing, rendered movement possible in the different parts; but even these inferior roofs had in many cases retained their shape in falling and were still used as huts of temporary refuge by the inhabitants. The enormous timbers used in the *temple* roofs, enabling stronger and stiffer joints without appreciable weakening of the structure, to a great extent compensated for the absence of triangles (see bottom of Fig. 37).

The writer has elsewhere had occasion to draw attention to the utility of this principle of double trussing applied to modern roofs for structures in earthquake countries, and which since the fatal earthquake of 1891 he has adapted to several important buildings. He does not by any means desire to advocate the copying of Japanese roof construction, an interpretation which one critic has chosen to put upon his observations. Such roofs are in many respects eminently unscientific, unnecessarily heavy, and wasteful in material, and they at the same time require numerous internal supports. But in the one particular of being equally stiff in both directions they present an important advantage. And this solidity and stiffness can also be given to modern structures executed in a more scientific and economical manner. The problem becomes a somewhat complicated one in dealing with roofs of buildings of irregular and compound plan. The plain square or oblong plan invariably given to Japanese buildings is very favourable to such treatment; but the principle is capable of application more or less to any plan.

To no part of a building did an architect perhaps give less attention than to the roof construction. The engineer, on account chiefly of the large spans and the iron construction with which he had mainly to deal, calculated and considered carefully every part of the surface of his structure. It was the common practice of architects to provide a general roof plan showing the positions of trusses and to supply only one or two details of individual trusses. These trusses were probably designed and calculated with considerable care, but in framing the whole roof together on a complicated plan, half-trusses, three-quarter trusses, diagonal trusses, and numerous unforeseen struttings, supports, and modifications were required which were left mostly to the contractor or clerk of works to devise. The consequence was that, though the roof truss alone might be a very strong and scientific structure, the roof as a mass was often a very weak and unscientific one. This was not attended with any serious results where simple weight and stability were concerned; but in case of structures liable to be violently lifted and shaken, it became most important to consider the roof as a whole. It should as near as possible approach the form of a hollow pyramid, equally unable to yield or move in either direction.

Continuing the inspection of buildings at Gifu, it was found that the Training School near to the Shihan Gakko had received considerable damage, many of the buildings having fallen flat. Part of the prison wall of the Gifu Jail had fallen, and remaining portions were much cracked, always at the brick joints. The prison wall was a brick structure about 18 feet high, and 2 bricks in thickness with corbelled brick top, tile-covered, and internal buttresses every 9 or 12 feet. The wall on the outside rested upon a sloping base of stone boulders forming the escarp of a small outer moat (see Fig. 38). One corner of this wall had a brick building attached, and on this account had bulged out considerably, cracking the adjoining wall.

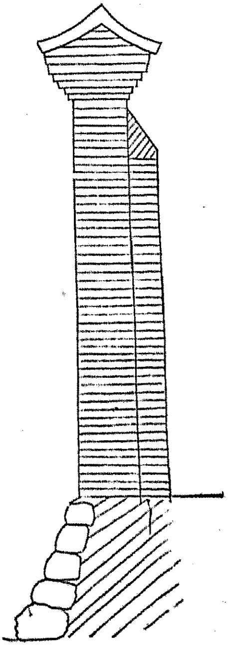


Fig. 38.

The Post and Telegraph Offices in Gifu and other wooden buildings of so-called European style remained erect, though much damage had been caused by fallen chimneys, and plaster had been cracked and shaken off.

The most important and monumental of the purely Japanese buildings in Gifu was the Hongwanji Temple; and, contrary to the experience in similar structures at and near Nagoya, this had been considerably damaged (see Fig. 39).

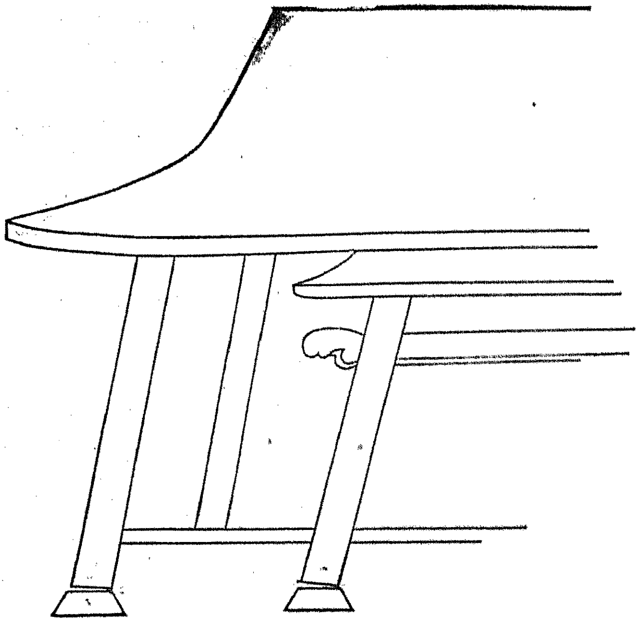


Fig. 39.

The Hondo, or Principal Oratory—of very massive wooden construction—was leaning over about 18 inches at the top, and a great part of the plaster had fallen off. Some of the large pillars had settled, showing signs of bad foundations.

The bending over of this structure, which like most Japanese buildings consisted entirely of framed parallelograms, was accompanied by openings and fractures at the points A. above, and B. below in Fig. 40.

A large Bell-tower on a double-staged stone-faced mound or platform had been thrown over and completely broken up, the bronze bell being projected some distance. The posts of this tower or shed showed very small pins or tenons which had been let into the stone bases (see top Fig. 40).

The Kodo or Lecture Hall, a building of considerable solidity, had fallen.

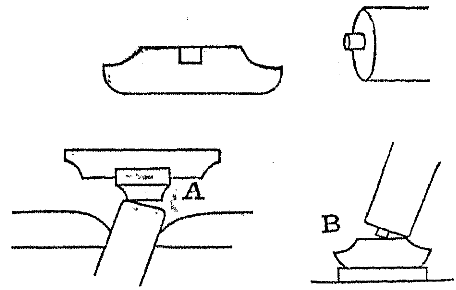


Fig. 40.

Close by, an interesting example was observed of a two-storied structure the upper stage of which remained vertical and apparently undamaged whilst the lower one was bent and reeling (see Fig. 41). The upper story being, like many Japanese two-storied structures, of smaller plan than the lower, the posts were not continuous the upper pillars being carried on heavy beams supported by the lower. Hence the hinge-like action which had taken place. The ornamental and somewhat solidly constructed porch of the priests' residence had also been much bent and twisted (see Fig. 42).

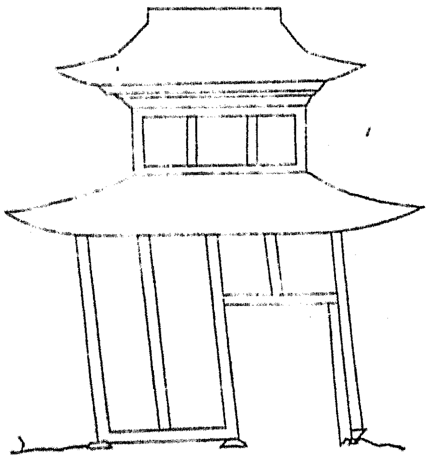


Fig. 41.

Another example was here noted of gate posts scarved to granite bases let into the ground, and in this case, though the granite base was root-shaped, (wider below than above), it had been drawn out bodily from the soil (see Fig. 42).

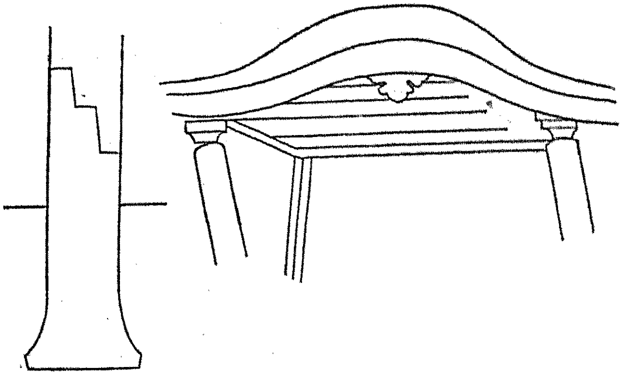


Fig 42.

Conclusions drawn from the above inspection of the buildings of Gifu were as follow :—The violence of the earthquake shock appeared to have been greater here than at Nagoya, a large rent in the ground being observed running right across the town. It was an undoubted fact that Gifu was much nearer to the centre or surface-source of the convulsion, which the writer in his itinerary was gradually approaching. All accounts show that the noise accompanying the catastrophe was much louder here than at Nagoya. It was necessary therefore to bear all this in mind in comparing the effects upon buildings with effects on similar buildings at a greater distance. The dislocation of the Hondo of the Hongwanji,—a structure of the same construction and colossal solidity as the temples which had resisted so admirably elsewhere,—might be attributable to the greater degree of commotion. It might also partly have resulted from looseness of soil and imperfect foundations,—a cause to which certain indications seemed to point. Other effects seemed to show that the jointing of the timbers was more defective than usual and the buildings in a rather old and comparatively neglected state.

However this might be, the dislocation which had taken place revealed clearly the weak points of all Japanese wooden structures, which in ordinary buildings had invariably been the cause of ruin, but which in certain exceptional and monumental structures had been neutralised by excessive strength and weight.

The writer of the present record desires as much as possible to avoid all controversial matters, but he feels bound to state as his opinion that there is nothing in the character of the wall framing or of the isolated foundations of purely Japanese structures which gives them any seismical advantage over European methods of framing and foundation. And this is amply and repeatedly proved by the effects of the earthquake of 1891. The advantages which such buildings may possess are entirely those of suitability to custom and climate. The instability of the parallelogram form of structure, liable as it is to rhomboidal change or deplacement, is repeatedly observable, as may at any time be seen in a broken or creaky chair; and Japanese wall framing consists only of parallelograms. The same applies to Japanese roof framing; but, as already pointed out, such roofs have another compensating advantage namely that of transverse framing which gives them additional unity and stiffness. The abstract theory that looseness of joints and liberty of movement is an advantage,—that the convulsive forces of nature are so irresistable that they cannot be combatted by weight and stiffness, and must, on the contrary, be met and neutralised by pliability, is a very plausible one, and one which is possibly to some extent applicable in practice. But if such looseness and pliability is unavoidably followed by breakage and disintegration, or by a change of form which destroys equilibrium and produces collapse, it is eminently useless and destructive. Foreign framed wooden structures, and even exceptional Japanese structures containing triangular arrangements of struts and braces, had on the other hand everywhere preserved their forms.

The example referred to of a two-storied structure, the upper portion of which remained erect while the lower supports had leaned over considerably, afforded interesting food for reflection. It confirmed the report that in certain two-storied Japanese structures the upper story had fallen bodily, and being at no great height from the ground had caused less serious injury to the inmates than was occasioned to those in the story below. Was not this then a case where looseness of connection offered a practical advantage? In structures of such a character that the lower stages must inevitably give way and let fall the superstructure the advantage seemed to be one of very slight degree and one which might in cases be attended with most serious results. But in applying European principles of diagonal framing to the lower stages and thereby rendering them incapable of rhomboidal displacement and collapse, the partial disconnection of the upper stages might certainly have its advantages. What the writer has called the *hinged* movement could indeed no longer take place, but the vibratory force and oscillation from below would be interrupted and not transmitted to the upper portions in a swing, increasing in proportion to the height, as in a continuous wooden structure. Possibly this principle was one capable of some application.

With regard to brick structures, the injury to the Gifu Jail wall pointed to the necessity of greater thickness or of larger and more frequent piers to long masonry walls where cross walls were absent. It also suggested the inadvisability of unnecessary ornamental projections increasing the top-heaviness of such structures. The matter of the quality and adhesiveness of mortar seemed also to require attention, as all cracks and fractures had occurred at the joints of the brickwork. This wall also afforded another example, frequently observed, of the weakness at the junction between light and heavier masses, the oscillation of which must be of different period and force.

As the only brick building of Gifu which had been seriously damaged, was in a condition of incompletion at the time of the convulsion, the brickwork being still damp, the mortar unhardened, and the walls unconnected by roofs and floors, it could hardly afford much instruction to practical observers.

From Gifu an excursion was made to the Neo Valley, at the further extremity of which had been felt the most violent convulsions accompanied by a terrific noise at the time of the earthquake, and by extraordinary changes of the configuration then and subsequently. Everything pointed to the extremity of this valley as the centre of the convulsion, or rather the superficial centre, for it must be assumed that the real centre was underground. The writer has elsewhere recorded his observations on the extraordinary physical phenomena witnessed in the journey up this valley, indicating that there were evidences of an immense subterranean subsidence having taken place, accompanied by a cracking and renting of the thinner crust of the valley, and resulting in throwing the surrounding mountains out of equilibrium. The small earthquakes, which followed the original convulsion, in numbers daily decreasing, proved by actual observation and experience to be caused by enormous superterranean landslips occasioned by the overbalanced hills resuming their equilibrium. No doubt the cracked and fractured condition of the soil, together with the existence of still unclosed cavities below, caused the vibration from such avalanches and landslips to be transmitted to greater distances than would otherwise be possible. The present record is, however, chiefly concerned with the effects of the earthquake upon structures, and speculations as to its physical causes are outside the matter in hand.

The village houses on the road from Gifu to the Neo Valley were constructed with stout posts and heavy timbers, as is common in country parts, where timber is more plentiful and employed with less economy than in the ordinary buildings of towns. These village houses had, however, nearly all collapsed, the high pitched thatch roofs retaining their shape on the top of fallen walls and posts. A large village called Kurono showed dreadful ruin, the common houses having all fallen, and only a few bent and staggering buildings of better construction remaining *in situ*. In Inuzaka village, the houses were a little better preserved. In the village of Monju a large school was shattered, the local temple and all the houses had fallen. The village of Yamaguchi marked the entrance to the Neo Valley. Only one or two houses of the better class, including the principal hostelry, were habitable, and these were much damaged A little beyond, large rocks from the limestone cliffs above had fallen and blocked up the roadway. In the rounded and less craggy hills on the side of the valley, large bare places were visible where landslips had occurred. In a sort of knoll, partly surrounded by large hills, a few farmers' houses, very old and poor in construction, remained undamaged, and the road passing near them undisturbed in any way. This was curious, and pointed to the possibility of explanation by theories of earthquake shadows. Could the weight and mass of intercepting hills in the line of convulsion have stopped or diverted the movement under their immediate shelter? Another point which was casually noted was the existence of a large grove of bamboos near these houses, and the coincidence that ancient tradition attributed immunity from earthquake to the vicinity of bamboo groves! At Sawara village, a little further on, the houses were all tossed over and the road much cracked. Beyond this the village of Kimbara was reached, and this marked the limit that it was possible to proceed in *jinrikisha*, the rest of the journey having to performed on foot. The houses here were a confused heap of *débris*, and even a large temple called the Ensho-in had fallen in fragments, the gate-frame alone remaining standing. Similar total ruin to dwellings had occurred at the villages of Midori, Kōdō, Kadowakimura, and Nagamine. The wells at Nagamine had all dried up. At Nojo, higher up the valley, the ruin was if possible worse, though many of the farmer's houses had been built with pillars of *keyaki* and *hinoki* 9 inches square. The guide who accompanied the writer from this village stated that his house, which was strongly built, had been moved or rather thrown forward bodily some 6 feet during the shock, he being seated inside at the time; it was much twisted and injured but did not fall over. The motion here, it was said, seemed almost vertical. This was the last village reached before entering the Fuji-dani, or extreme hollow of the Neo Valley, bounded at the top by the mountains dividing it from the province of Echizen.

Reflections arising out of the observations in these localities of greatest commotion were;—That structures which showed considerable powers of resistance at more distant points, where the movement though violent was more horizontal and undulatory, were helpless against the vertical shocks or upheavals at the localities of greatest disturbance.

After examining the remarkable physical phenomena which had occurred at this supposed centre of commotion, the return was made by the same route to Gifu.

On the road from Gifu to Ogaki similar destruction to buildings was observed. At the village of Minato the street was cut up into rifts, the houses shattered to pieces, and a bridge near here over the Nagasegawa knocked into waves both laterally and vertically. Even solid temples and their gateways between Gifu and Ogaki were destroyed, the ground being severely cracked. The few fireproof stores which remained standing were stripped of their mud and plaster.

The town of Ogaki, consisting of about 8,000 houses, had very few structures remaining standing. Perhaps 30 would have been a very full computation, and even these were much damaged and in an unsafe condition. One temple was observed half standing, the other portion having been torn away and thrown over. The numerous wooden bridges across the river passing through the town were all broken. The greater proportion of the fallen houses were burnt, and it was stated that a large number of people were burnt alive. One large conflagration and five or six smaller fires broke out immediately after the earthquake. People only injured or imprisoned by the falling timbers and roofs of their dwellings were surrounded by flames before they could be extricated, others scatheless from the earthquake, but bent upon rescuing their companions, themselves fell victims to the encircling conflagrations. The destruction also of the so-called fireproof structures, which a fire unaccompanied by earthquake invariably leaves standing, made the destitution of the survivors pitiable in its completeness. Among the few structures remaining was the Castle Keep, which had been severely shaken, the finial tiles falling off. The adjoining Tamon were much damaged, leaning over in a S.W. direction, and the stone-faced escarps were destroyed.

The Police Office, a wooden building of mixed Japanese and European style, had its central projection broken and leaning (see Fig. 43). The Post Office, a wooden plastered building in European style, showed signs of severe shaking, the joints of the frame-work being broken and the plastering damaged, but it preserved its erect form.

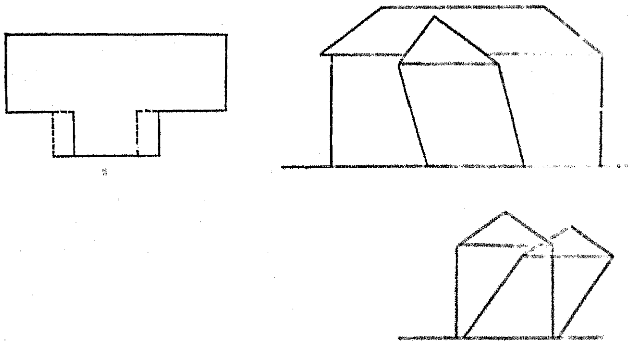


Fig. 43.

The Jail, an old and strong Japanese building, was not much injured, but the central part of the administrative office had fallen down in a N.W. direction (see Fig. 43). The prisoners work-rooms were bent over. A wealthy wine merchant's shop called *Inabaya*, being a very strongly built Japanese building, newly erected, with thick posts, was hardly damaged at all. There were also several examples of two-storied structures in which the upper story had fallen bodily and remained almost erect upon the scattered timbers of the lower. Certain old and rotten wooden fences, curiously enough, remained in position.

It was impossible to visit the town of Ogaki as well as Gifu and Kasamatsu without being impressed with the serious calamity from fire, following earthquakes, in cities mostly constructed of wood. Any mitigation of injury owing to the lighter weights of falling wooden structures, as compared with the partial collapse of buildings of heavier materials, seemed to be far outweighed by the subsequent total destruction of property and the torturing death which conflagration occasioned.

From Ogaki an excursion by railway was made to the large city of Osaka. Though a considerable distance from the source of convulsion, Osaka had been very severely shaken. So violent, indeed, had been the shock that all recording instruments in the Observatory were broken, and many of the residents affirmed that it was impossible to stand or walk in their rooms during the most violent period of oscillation. The intensity of the earthquake in this locality was amply proved, moreover, by the serious injuries which certain buildings received. It may be argued that being so far removed from the Neo Valley—the supposed centre of commotion—the test given to buildings of different classes was not sufficient—that in fact constructions which escaped serious damage in Osaka would have been overthrown if standing in Nagoya or Gifu. This is no doubt so, but in the following records and observations upon the Osaka structures it is not intended to imply that those constructions which showed admirable powers of resistance could have endured, equally well however violent the convulsion. Where such phenomena are concerned the architect cannot aim at absolute, but only at comparative, safety. Osaka afforded a particularly favourable opportunity for examination and enquiry, because it contained numerous buildings of all classes in all kinds of localities, and since the earthquake, as experienced, was, to say the least, unusually severe, a comparison of the injuries to different classes of buildings was most useful and instructive. Particularly was Osaka the best and only field for arriving at fair and useful conclusions as to the comparative seismical strength of different classes of *brick*, *stone*, and other *fireproof* buildings. Being one of the largest and wealthiest capitals of the Empire, it contained, in addition to fine monuments in the old ligneous style, important modern structures in brick and stone. Some of these were of the manufacturing, commercial, and speculative class, in which a minimum of outlay and solidity had been aimed at, whilst others were more of the national or monumental class. On the other hand, the few brick buildings in the provincial towns, most of which had been seriously injured, were generally of the cheapest speculative class erected for manufacturing purposes. Those, even, which came under the head of Government erections being almost equally defectively built on the principle that what was necessary for the larger and wealthier cities was too good and expensive for the smaller towns.

The first building inspected in this city was that of the Electric Lighting Co. in Nakashima 3 chome. The tall brick chimney, about 125 ft. high, had suffered considerable damage, a portion about 15 ft. long at a height of 72 ft. had opened in the side in a fissure about 5 inches wide (see Fig. 44.) No crack was observable above this fissure, but cracks extended below it to a point about 60 ft. from the soil. The chimney was in a dangerous condition, and it had to be taken down as far as the bottom of the fracture. It had apparently been substantially constructed, being 2 bricks thick at the top, then 3 bricks, and 4 bricks thick at the bottom. It rested on a wide footing above a concrete base 28 ft. square, the concrete being composed of 1 part Osaka cement, 3 of lime, and 5 of granitic sand and gravel. Below the concrete were close piles 18 ft. long.

An examination of detached portions of the brickwork showed that the mortar itself was pretty hard, but did not adhere properly to the bricks. Some portions of the bricks, especially the vertical joints, were quite clean. The inference was that the bricks had not been properly soaked, and these vertical joints not properly filled with mortar when laid.

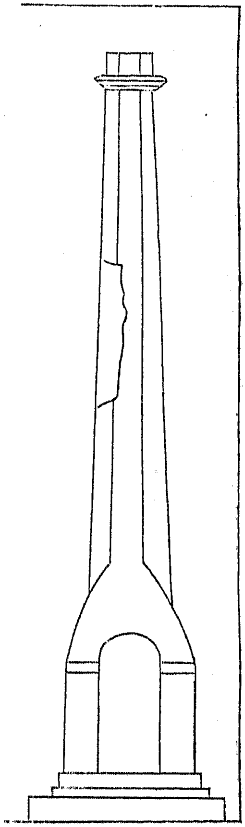


Fig. 44.

The brick Boiler Room, 40ft. and 57ft. in plan, and 22ft. 6in. high to the tie-beam, showed no crack whatever. The walls were 2 bricks thick, with the exception of one end filled temporarily with woodwork with a view to the extension of the building, and there was a divisional wall from the Engine Room 2½ bricks thick. The walls contained medium-sized windows reaching a little more than half way up to the eaves, with broad piers between. The building was covered by a roof of flattish slope and king-post construction, with a

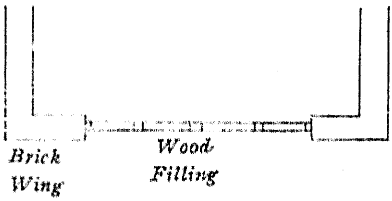


Fig. 45.

lantern. The ends had brick gables with trusses against the inside of the gables.

The Dynamo Room, also of brick, measured 50ft. by 71ft. 6in. on plan and was 20ft. high to the cornice. It was also intact. It was constructed with outer walls 2 bricks thick and a divisional wall 2½ bricks thick; and had semicircular, headed windows to about half the height of the wall. One end of the building had short brick wings with wood filling (see Fig. 45). It was covered by strong king-post roof trusses, with a large transverse beam supporting them in the centre, carried on two central posts. These buildings had been superintended in their construction by Mr. Takahashi, an experienced foreman, who had been engaged on the Osaka Mint.

The Sangenya Cotton Spinning Mills at Osaka, next examined, consist of three large Mill Buildings, Mill No. 3 being the largest and latest built, executed entirely from working drawings and specifications prepared in England by Messrs. Hicks, Hargreaves & Co., of Bolton in consultation with Mr. Yamanobe, the Manager of the Mills, then in England. It was superintended by an English Clerk of Works, with whom worked Mr. Sasaki as Japanese technical superientendent. This building was four stories high—about 67 ft. from the ground to the cornice, with a tower still higher—about 87 ft. to the cornice. The size of the main block was 96 ft. by 170 ft., having four internal rows of cast iron columns suppporting floors and roof. Together with the staircase turrets the area of this block was about 885 *tsubo* (31,860 sq. ft.). Attached to this block was the Engine House about 67 *tsubo* (2,412 sq. ft.) in area. The total cost of this Mill, including imported building material, was said to be $180,000, of which the Engine House cost $2,500, coming to about $500 per *tsubo*, and the Mill proper costing about $175 per *tsubo*.

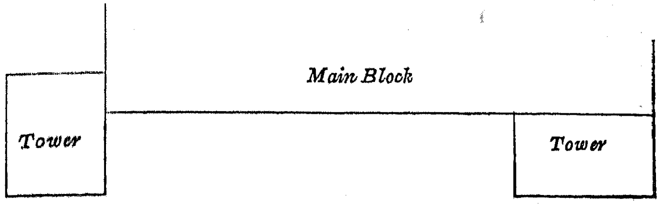
These prices are important to those familiar with ordinary building prices of a similar class of structure in Japan for purposes of comparison. This No. 3 Mill had been built strictly in accordance with working drawings supplied by an experienced Firm in England, and in the same manner that such a large and high structure for heavy machinery would be built in that country, cast iron, wrought iron beams, and cement being specially imported. Other companies in Osaka and the neighbourhood had followed it as a model for the general arrangement of their buildings, using their discretion in thinning walls, modifying floor construction, and practising various economies in construction. Probably the cost of the later Cotton Mills, some of which had severely suffered in the earthquake, was less than one half the cost per square foot of area of the Sangenya Mill. To return to the description of this gigantic Mill, its main walls were 4 bricks thick (2 ft. 10″) on the ground floor, 3½ bricks on the 1st floor, 3 bricks on the 2nd floor, and 2½ bricks on the 3rd floor. Below the ground the outer walls were 3 ft. 2″ thick, and 5ft. 8″ at the bottom of footings. The concrete trenches were 7 ft. wide, filled with cement concrete made with British cement; and below the concrete were 18ft. piles 6″ in diameter driven by machinery into the sand. Concrete beds and piles also existed under the internal cast iron columns. The Engine Room had outer walls 5 bricks thick to the top of the engine beds, and 28 ft. high from the top of engine beds to the beams of roof,—altogether 40 ft. high from the concrete to the eaves. The elevations showed large windows on all stories, the wall spaces between which were only a little more than half the width of the openings, and these were crowned by flat segmental arches. The tower windows were narrower and their arch curves apparently struck from the same centres as the larger windows, being almost straight. The Engine Room, however, which had been designed as the chief ornamental feature of the design, had some large semicircular-headed windows. The walls were crowned with a machicolated cornice of considerable projection, and a parapet, solid in the main central portions so as to form a tank-roof, but balustrated at the corner pavilions.

The framework of the floors and main roof were similarly constructed, with strong iron girders placed about 4ft. apart, and filled in with half brick arches concreted above. The flat roof was asphalted above the concrete with Belgian asphalt and, enclosed by the solid parapets, formed a large reservoir continually filled with a few inches of water, to prevent cracking.

One of the staircase towers supported a large iron water-tank, its walls being about the same thickness as the walls of the main block, with the addition of half brick projecting piers on the exterior. It had a low pyramidal roof constructed of wood and covered with tiles. A divisional brick pier ran up the centre of this staircase tower, but it terminated 10ft. below the bottom of the tank, which was carried 3 inches free of the outer walls, supported by stout iron girders (compare with description of Owari Cotton Mill pages 28, 29).

Effects of the Earthquake.—The shock was so severe that the short tenons of the struts of the tower roof were shaken out of their mortises. A large crack was observed at the end of Engine Room in the wall forming the division between it and the Rope-chamber, but the Manager stated that this was an old crack due to unequal settlement during construction. The upper part of the Engine Room had been delayed in construction owing to difficulty in procuring stone from the quarries, and the weights being unequal a crack had occurred between this annex and the main building. This original crack had been strained and widened and a few bricks crushed by the earthquake. In the Main Block, the two towers had small window openings close to their junction with the main wall, and the very flat arches of these openings had been strained and damaged, the keys falling out. Of these towers one had only partial connection with the main block (see Fig. 46). The arches referred to, which were damaged, were mere facing arches of only a half brick penetration.

The mortar of the brickwork was common lime mortar, and it apparently had good connection with the brickwork, except in the vertical faces of the bricks, which were clean. The bricks were made at Sakai and had frogs in their beds.



Fig, 46.

Some of the brick arches of the top floor and roof had opened a little in one place, letting in the water from the flat tank-roof. The iron girders and joists carrying these arches were built into the walls without any anchoring. The larger girders had cast supports for receiving the ends of iron joists. The tops of internal door openings were supported on iron lintols and in one or two cases the movement of these, or the vibration of the brickwork in contact with them, had caused cracks in the brickwork. Slight injuries had occurred to the parapets at the corners of the building, which were constructed of thin brick balusters supporting heavy stone copings.

The above observations showed that the building, although of unprecedented height for Japan, had suffered comparatively little damage from the earthquake, and the writer can but attribute this mainly to its solid, careful, and conscientious construction. The light flat roof, having a skeleton of iron beams and acting as a fixed lid tying the top of the building, probably presented superior advantages to the ordinary sloping roof of heavy timber and of more or less independent trusses. The network of iron beams at the different floors, though not anchored, acted as important horizontal ties to the walls, without creating the large cavities occasioned by the use of enormous wooden beams; and the brick arches and concrete over these prevented them moving independently and battering the walls. Though the window openings were of large area compared with the wall spaces, a great thickness had been given to the intermediate piers.

On the other hand, such small injuries as had resulted pointed to the following conclusions :—Damages had occurred at the junction of towers of small mass with the large mass of the main block. The main block had oscillated practically in one piece, and had strained the junctions with these smaller masses, the tendency of which was to oscillate with a different period to the main block. Openings close to these points of connection proved additional sources of weakness. Having in view earthquake alone, it seemed important that the plans of buildings should be as simple and compact as possible, all offshoots from the main figure of plan proving points of weakness, and in proportion to their smallness of size as compared with this main plan, and in proportion to their limited connection with the main block; short, of course, of complete detachment.

The flatter the form of brick or stone arches to openings, the more they appeared liable to injury from the strains caused by earthquake. When these arches were mere surface arches, of small penetration, they were still more liable to displacement.

Arches of good curve forming a solid ring right through the thickness of the wall could hardly fail to strengthen openings, especially if they could be made constructively continuous with the jamb and cill borders. They would then somewhat resemble in function a rim added to strengthen the edge of a hole in glass or porcelain. On the subject of arches to wall openings much has been written assuming a permanent state of pressure and thrust such as exists in a model arch constructed of loose blocks weighted above ; and upon this assumption the agitation and disturbance of equilibrium caused by earthquake is supposed to render the arches of doors and windows a source of active injury to the walls. Accordingly, lintols have been recommended for spanning apertures, in preference to arches, as being always in a state of repose, whilst arches are in a dynamic condition. Experience, however, shows that the arch of the ordinary door or window-opening in a well constructed brick building, the material of which has properly set, becomes a solid and continuous border to the top of the aperture, very little, if any, of the superincumbent weight being converted into thrust along the arch. Except in the case of very wide openings, the arch could in fact be afterwards removed and the solidified brickwork above would hold itself together. If the aperture were of pointed form, the superincumbent wall would be less likely to yield and crack on the removal of the arch than if it were of semicircular form; and again, the semicircular form would be more self-supporting than the segmental and the straight forms. It is, therefore, the form of the openings which has to be first considered, and the arches may be regarded as borders giving additional strength to the edges of such openings.

The writer is convinced that other conditions being the same, the square head is undoubtedly the weakest form for the top of an opening, and the segmental, eliptical, semicircular, and pointed forms excel in strength in the order given, the pointed being the strongest. But the application of any such theory must be strictly governed by other considerations, such as the area of the openings in proportion to wall areas and the width and strength of intervening bands of brickwork. A pointed or semi-circular head to an opening might in certain cases so cut into the intervening horizontal bands of brickwork—already sufficiently weakened by the penetration of floor or roof beams—that a segmental head might be preferable for the united strength of the building. The strongest form for window openings in a given building could not therefore be determined independently of the exact distribution of such openings.

Regarding the brick arch over a window as the top border of an aperture, (which forms a void or point of weakness in an otherwise solid wall) the edge of which aperture is subject to compression, tension, and wrenching, by the vibration of the surrounding brickwork, it is plain that, being constructed of separate blocks, it is liable to open and crack when stretched and sheared. At the same time it may be assumed to shield the top of the aperture, the edges of which would have become much more damaged without its protection. Its value, as well as its own immunity from injury, would undoubtedly be increased by the employment of good bond giving it a maximum of tensile resistance, and it would be rendered still more effective by making it constructively continuous with the side and bottom borders of the opening. Probably it would be to the advantage of such a continuous rim or border to an aperture that it should be as nearly as possible of the same material as the surrounding walls—possessing the same amount of elasticity; but if window openings were lined with a continuous frame-border of wrought iron throughout the thickness of the wall, serving at one and the same time as arch, jambs, and cill, the writer is of opinion that this would be a valuable protection during severe earthquake.

On the other hand, rigid iron lintols alone, the ends of which must perforce penetrate the sides of the opening, could not be considered satisfactory. In cases where they had been employed, their penetrating ends had seriously damaged the corners of the apertures which they covered. Wooden lintols proved to be equally or even more injurious to the tops of doors and windows during seismic movement (see Fig. 13 page 24). The same applied in a greater degree to lintols of stone which were invariably only loosely, connected with the brickwork at their backs, and created considerable disturbance during vibration.

The damage occasioned to the pierced parapets of this building, pointed to the necessity of making parapets as solid and coping them as lightly as possible. The solid low parapets over the main block had not suffered, nor had the heavily projecting machicolated cornice. This was doubtless attributable to good construction, and especially to the absence of the heavy slooping wooden roof, which had pushed out the cornice stones in so many other buildings.

Mill No. 2, in the same compound, was an older building, only three stories in height, but of somewhat larger area than Mill No. 3. The outer wall was three bricks thick below, two bricks and a half on the first floor, and two bricks above, with cross walls two bricks thick running up through two floors. On the façade the lower story had large windows with semicircular heads, and the upper stories double windows of smaller span also crowned with round arches. The building was covered by three spans of king-post roofs, and these, as well as the floors, were supported internally on four rows of stout wooden posts with cushion caps. The beams of the floors were framed in both directions, giving the advantage of great stiffness. The ceilings were formed of sheet iron strongly screwed to the beams.

In this building, the floor and roof beams had been slightly loosened and the walls slightly cracked at their points of penetration, but no other injuries appeared to have occurred.

No. 1 Mill, a comparatively low brick building with walls two bricks thick and small windows, was undamaged.

A brick chimney, about 120ft. high, cracked so much at the top that 25ft. of its length had to be taken down. On close examination, very small cracks were to be observed extending considerably lower than the 25ft. and running spirally round the chimney.

The next buildings examined were those of the Kanakin Seishoku Kaisha, carried out under the superintendence of Mr. Ohara, Architect, a graduate of the Imperial College of Engineering, from plans supplied by Messrs. Platts and Oldham, England. The work was executed by small contracts for the different trades. The bricks were from Sakai. The building was of two stories, of a total height to the eaves of 32ft. 6″, measuring 126ft. by 132ft. in plan, with walls three bricks thick below but only one brick and a half above. The floors and roof were supported internally by 66 wooden pillars, 6 in a row, in one direction, and 11 in a row in the other. The roof was of very flat slope and lightly covered with galvanized sheet iron. The other building was a one story brick shed

154ft. by 132ft. in plan, and 14ft. high to the tie beam, covered with zigzag roofing, supported internally by rows of columns 11ft. and 22ft. apart. Between these two departments was the Engine and Boiler Room, 60ft. by 35ft. in plan, with walls 2 bricks thick and 18ft. high. The foundations were on piles driven into firm sand. The principal building was peculiarly constructed in its upper story, the roof trusses and roof plates supported upon wooden pillars built against the 1½ brick walls, a space of 5″ being left between these pillars and the brick walls (see Fig. 47.) This space is reported to have opened as much as 2ft. during the earthquake shock, the roof and supporting wooden pillars swinging independently of the brick walls.

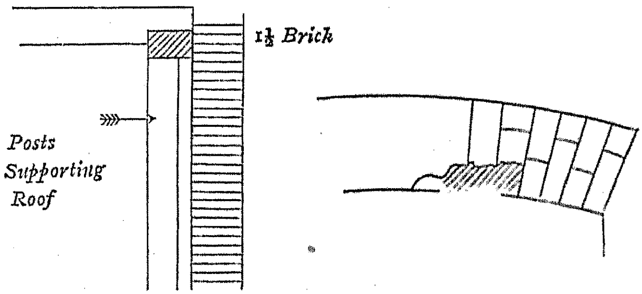


Fig. 47.

The floor frames consisted of wooden beams 11ft. apart, carrying solid boarding 3½″ thick without joists. Over this thick boarding was spread a layer of mortar or fine concrete 2½″ thick, and upon this ordinary floor boarding was placed. The weight of the machinery had crushed out some of this mortar filling (see Fig. 48). The floor beams were let into shallow iron socket-caps attached to the tops of the wooden pillars. In some cases the pillars had come out of the shallow sockets. Certain partition walls in the building which were one brick thick had cracked and opened at their connection with the outer walls.

According to all accounts, the amount of oscillation in the brick walls of the highest building had been intense, and as it could hardly be said to be of first class construction, it was surprising that so little damage had occurred, only a few arches being injured (see Fig. 47). The lightness of the flattish roof and the moderate size of the openings had no doubt been favourable. Some architects have been inclined to detect a virtue in the method of constructing the upper story with wooden pillars free from the brick walls, carrying the wooden roof. Considering the report made by eye-witnesses, that the brick walls and woodwork had opened as much as 2 ft. during the shock, and also

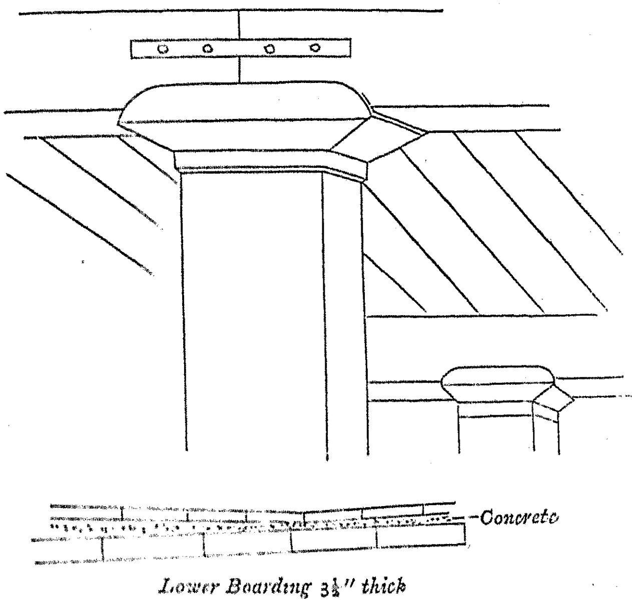


Fig. 48.

in the light of observations elsewhere showing the injury done to brickwork by moving and battering timber, the writer can hardly consider such construction to have been advantageous. It seems to him almost miraculous, when compared with other experiences, that the upper wooden skeleton did not injure more seriously and even actually push over the thin upper brick walls, and he thinks that it was probably "within an ace" of doing so.

A visit was next made to the Naniwa Cotton Spinning Mill—the building in Osaka which had been most seriously damaged, causing considerable loss of life. It was a comparatively new building, finished in November 1890—about a year previous to the earthquake. The plans of the Sangenya No. 3 Mill, to which the Naniwa building presented a strong family likeness, were lent as a guide for its arrangement and design, and it was constructed by the Kansei Kogyo Gumi of Osaka. The writer made enquiries, but was unable to learn of any architect or experienced foreman engaged in its construction. The cost, including cast iron columns, was about 120,000 *yen*, or a little over 100 *yen* per *tsubo*—a little more than half the price of the Sangenya Mill. It was a three-story Mill, 120ft. wide by 300ft. long, with two staircase towers, and an Engine Room and Rope chamber at the end (see Fig. 49). Internally it had five rows of cast iron columns in its width,

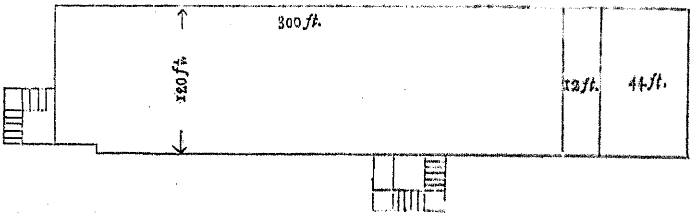


Fig. 49.

and twenty-one rows lengthwise. These columns appeared to be rather thin in proportion to their length. They rested one upon the other, the wooden floor beams, 13 inches deep, being supported upon shoes attached to them. The beams were crossed by stout joists 2 feet apart, carrying thick boarding, and they ran loosely into the brick walls to the depth of 6 inches, being additionally supportedon stone corbels. The walls of the different stories were 2½ bricks, 2 bricks, and 1½ bricks thick respectively, with the addition of piers of ½ brick projection externally. The total height from the ground to the cornice was 57ft. 6in., and to the top of parapet about 60ft. The wall surfaces were thickly perforated with windows, some 5ft. and others 7ft. or 8ft. wide, leaving narrow piers considerably less than the width of openings, and narrow bands of brickwork between the different window stages (see Fig. 50). The foundations were said to be built upon soft, shifting sand, upon 15ft. and 12ft. piles, with concrete over them. For the walling, common lime mortar was used throughout, and no cement work.

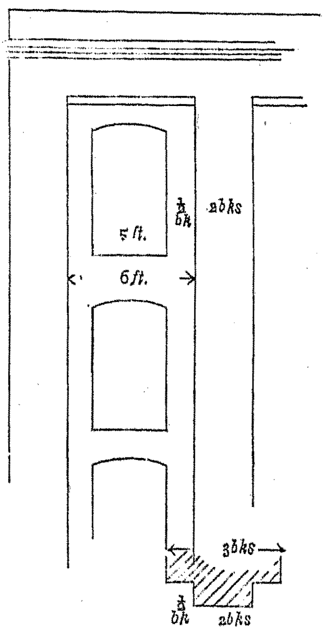


Fig. 50.

The effects of the earthquake upon this building were as follow:—The oscillation of the wooden floors, weighted with heavy machinery, had apparently been the cause of pushing over a large portion of the upper walls of the building, which were of minimum thickness, crowded with apertures, and not in any way tied together by iron beams or cross walls. On the North side of the top floors, which has been most heavily weighted with machinery, the floor beams had been pulled out of the walls, letting in the floor, machinery, and shafting. It was on this side that the collapse of the wall had been greatest, the whole of the third story and part of the second story being broken off to a point near the top of the windows of the first floor. The appearance of the line of fracture resembled the teeth of a saw. The upper wall of two bays at the East end, where there had been no machinery, remained standing. On the South side, the wall of the second story still remained, though much cracked and leaning, and having its point of junction with the upper floor very loose, with beams broken. A portion of the lower story wall, on the East side, had separated from the first floor, either the floor having shrunk inwards, or the wall being permanently pushed out. The outer walls of the end portion having the cross walls of Engine Room and Rope Chamber to tie and strengthen them, had not collapsed, and were but slightly injured. There were no signs of cracks in the foundations, although the portion over Rope Chamber, carrying the large water tank, was reported to have sunk 2 inches at the time of the shock.

People who were in the Mill during the earthquake state that two violent motions were felt, one from E. to W., followed by one from N. to S. The long sides of the building faced North and South.

At the junction of all floors remaining in position, the brick packing over wall plates were loosened, and beams and joists partly drawn out (see Fig. 51.) The bricks used were large Maiko bricks with frogs on both beds, sizes being 7 *sun* 8 *bu* by 3 *sun* 8 *bu* by 2 *sun* 5 *bu*. They were tolerably hard and all fractures in the walls had taken place at the mortar joints. Very few bricks were found to be broken, even in the fallen masses; and the cracks in the standing brickwork were all in the joints. The bricks in the walls remaining standing could, at the line of fracture, be easily separated by hand, the mortar having no adhesion. Their vertical joints and backs were quite clean, and the mortar adhering to the beds was easily rubbed off, crumbling to powder.

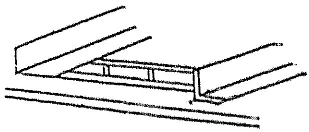


Fig. 51.

Conclusions drawn from the above observations, were :—That the walls of the building were too thin, considering their great length without any cross walls and in view of the large span of the Mill. The span was 120 feet, and the length of external wall, without cross walls was 300 feet. In the Sangenya Cotton

Spinning Mill (which was, however, one story higher than the Naniwa Mill) the span was only 96 feet, and the greatest length of external wall 170 feet, notwithstanding which, the walls were 4 bricks thick below, and 2 bricks and a half thick on the top story. The additional strength imparted by cross walls was illustrated by the fact that the end of the Naniwa Mill, containing Engine Room, Rope Chamber, and Tank Tower, had not fallen like the rest. The wooden floors, with large beams loosely penetrating the brick walls, supporting single joisting and not stiffened transversely by binders, did not act as horizontal ties between the walls as the stiff iron framework of the floors in the Sangenya building had done. In fact, these loose heavy floors, weighted with machinery swinging with the iron columns, alternately drawing out from and shoving the walls, seem to have been one if not the main cause of the collapse of the brickwork, already considerably weakened by the holes of the large timbers. This pointed to the advisability in such buildings of using light steel or iron floors, well anchored into the walls. If compelled to use wooden floors, they should be stiffly framed in each direction so as to form a united framework and the penetrating beams should be anchored into the walls. It is possible that the anchoring of beams into walls would in cases of intense oscillation cause considerable strain and injury to the brickwork at the floor line, unless the walls were of great thickness, but such local injury was nothing as compared with the damage occasioned by loose floor timbers, which were in turn drawn out of and rammed against the walls with great violence. Besides the thinness of the walls, they were additionally weakened by numerous windows, the apertures equalling in combined area that of the solid walls, and the pier widths being about one half of the widths of openings. In cases where such large and frequent openings were necessary, walls must be proportionately thickened. But one of the most serious defects of the building under consideration was the bad quality of the mortar used in laying the bricks, and the method of bricklaying. The vertical sides of the bricks were perfectly clean, not being even stained by mortar, which had been apparently smeared only on the beds. Even the mortar between the beds had no adhesion to the bricks, suggesting that they had been laid dry, a habit, as is well known to those engaged in practical work, most difficult to eradicate from the Japanese bricklayer, who has a most obstinate liking for liquid mortar and dry bricks. But the mortar itself was seriously defective, not only had it no adhesion to the bricks, but it had no cohesion in itself, and was easily reduced to powder with the fingers. The mortar joints had presented no resistance to the brickwork being pushed over, as might be seen by the form of fractures and the condition of the bricks at the line of fracture. The newness of the building, which was only one year old, may have partly accounted for this, but the mortar was dry, and although it cannot be said to have set, it seems unlikely that it would have ever hardened more with age. It seems probable that the lime was not properly or freshly burnt.

Another building inspected, said to be 2½ years old, was the Osaka Seigyo Kaisha, a two story building, 45ft. in span and 100ft. long, with walls 2 bricks thick from top to bottom. The walls were perforated with segmental arched windows 5ft. wide, with 5ft. spaces between. The upper floor was supported internally by one central row of pillars, the top was covered by a large queen-post roof of flat slope, covered with tiles, and entirely supported on the outer walls, and the outer wall was finished with a low brick parapet having heavy coping stones, and two end gables of brick and stone. It was observed that the brick walls of this building were awry having been carelessly built. The following effects from the earthquake were noted :—

The connection between the walls of the main building and adjoining Boiler Room had opened a little. The brick and stone parapet had been pushed over by the tie beams of the roof, and all the bricks round the ends of the tie beams had been cracked or loosened, in some cases large cracks extending down the walls below these timbers (see Fig. 52).

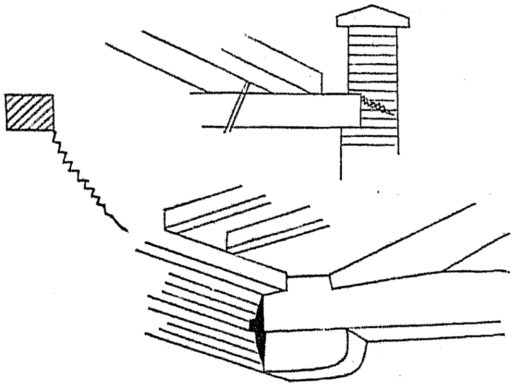


Fig 52.

The corner stones of the brick gable ends had fallen, being also pushed out by the vibration of the roof. The mortar was tolerably hard compared with that examined at the Naniwa Cotton Spinning Mill last described.

The Commercial Museum (Chinretsujo), a plastered brick building carried out from the designs and under the superintendence of Mr. Yoshii, Architect,—a graduate of the Imperial College of Engineering,—had not suffered to any appreciable extent. A few cracks had occurred in the plaster ceilings, and between the wooden partitions and the brick walls with which they were connected. This was the second plastered brick building which had been examined, the first being the Powder Magazine at Nagoya. Though both of these buildings had other sterling qualities sufficient to account for their freedom from damage, it was possible that the external plastering added a certain amount of cohesion to the brick walls.

The Senshiu Cotton Spinning Mill at Sakai was next visited. It was a new, three-story structure, commenced on the 7th March, 1890, and finished just before the earthquake, being superintended by Mr. Sasaki, the assistant architect of the Sangenya Mill, separate contracts being made for the different trades. The area of this building was 690 *tsubo*, the main halls measuriug 100ft. by 130ft. (see Fig. 53). The heights of the three floors were 16ft., 16ft., and 14ft. respectively, which, together with the depth of the floors, made a total height of 50ft. to the eaves, and of 55ft. to the top of the parapet. Below the parapet was a machicolated cornice of considerable projection? The thickness of the walls were 3 bricks below, 2½ bricks at the piers of the first floor, and 2 bricks between the piers, and 2 bricks at the piers of the second floor and 1½ bricks between the piers. The end wall of the top story, though shorter than the side walls, and having wider spaces between the windows, had for some unexplained reason been made one half brick thicker. The top wall of the staircase tower measured 3 bricks in thickness. A water tank on the top of this tower was carried on wooden beams supported in the outer walls, and crossing a central brick pier which divided the flights of the staircase. The windows of this building were about 5ft. wide, with intermediate wall spaces about 7ft. 6″ or 8ft. wide; they were crowned by segmental arches of rounder curve than those at the Sangenya Mill: some small windows had semicircular arches. The main hall had a Shaft Gallery attached to a smaller Hall beyond this as a special Mill; the Engine and Boiler Room was at the side (see Fig. 53). Floors were of timber

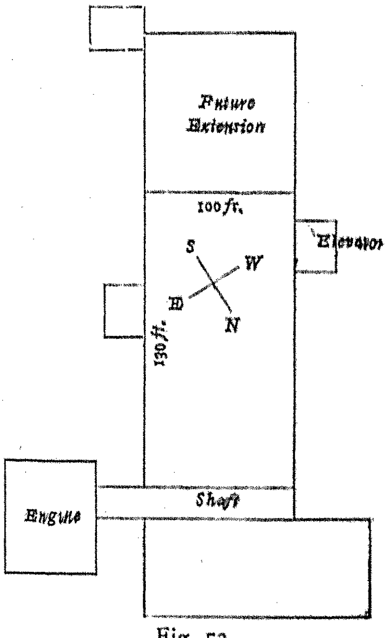


Fig. 53.

with deep beams and binders carried in iron shoes on four rows of cast iron columns, the columns bearing continuously one upon the other. The floor beams penetrated the outer walls about 9 inches. The roof consisted of five spans of king-post trusses covered with Japanese tiles.

In building the foundations water, was reached at a depth of 8ft. 6 inches, and piles 15ft. long and 6 inches in diameter were driven in three rows, concrete 5ft. thick being laid upon these to widths of 5ft. 6in. and 6ft. 6in. below the different walls. The concrete was made with a mixture of lime, cement, and river ballast. The bricks were manufactured in Sakai. The mortar of the brickwork contained also cement mixed with the lime, and as no mortar-mills were used, the ingredients were thoroughly mixed three times by hand.

People who were on the spot during the shock say that it was felt in this building very severely: the injuries were, however, very slight. The parapets on the N., E. and W. sides fell over in blocks, that on the S. side remaining. The roof was a little injured by a portion of the N. parapet falling inwards. The pole-plates of the roof were also loosened. The mortar of the fallen brickwork was found to be tolerably adhesive. The segmental arches of most of the windows were uninjured. The connecting arches between the Elevator Tower and the main block, and a few narrow segmental arches, were cracked and open. There was also a crack down the inside of the main wall at the point of its connection with the tower. These observations were confirmatory of what has been advanced previously with reference to the connection of unequal masses in the same plan. The walls had not been perceptibly injured by the floor beams; and it is worthy of remark that these floors were stiffly framed in both directions and the beams were deeply bonded into the walls.

The Panorama Building at Osaka had been in no way injured. Though a cheaply constructed brick building of no inconsiderable height—54 ft. to the eaves—from a seismological point of view it presented many advantages in form and detail. It was of circular plan, its walls presenting the form of a cylinder of elastic brickwork. It had no intermediate floors, and possessed a light roof covered with corrugated iron and glass. The thick wall-plate carrying the ends of the roof beams formed a continuous ring.

An examination was next made of the principal Government buildings of Osaka, the first establishment visited being the Imperial Mint, consisting of several different structures. The Office building, erected in 1883, was a low two-story brick building with walls 2 bricks thick and wide windows crowned with flattish segmental arches. The foundations were said to be 12 ft. deep, with piling and wide concrete trenches. The Mint proper—a much older building erected in 1869—was a high single story structure 225 ft. by 84 ft. in plan. The walls were built with ashlars of a volcanic rock called Tatteyama stone and measured about 15 inches thick between the piers and 2 feet thick at the piers. The mortar used was composed of a mixture of lime, cement, crushed coke, and sand, laid in fine joints. The height of the walls was 24 ft. and they were crowned by a stone cornice of considerable projection, above which the plastered wooden eaves projected considerably. The windows were circular-headed and there were concentric round arches connecting the external piers. The wall spaces were much wider than the openings. Large iron columns supported the roof internally, the ends of the tie beams being carried in strong iron shoes. The outer walls had a continuous roof plate. This main building was constructed upon piles driven into the sand, over which was a wooden platform carrying wide concrete. The footings over the concrete were 8 ft. wide at the bottom, constructed of long stones laid alternately in different directions. In the centre of the façade was a stone columned portico with inverted arches below the columns, and even this had not been damaged. At the eaves were several rather high chimneys, and these had been much cracked by the earthquake. The Assay Department adjoining had a wooden lantern-roof with an end gable of brick, and this gable had been pushed slightly out in a N.W. direction, some of the bricks being a little loosened.

The Copper Mint was a separate brick building, measuring externally about 48ft. by 45ft.; the greatest length between cross walls being 210ft. (see Fig. 54). These divisional walls had wide central arches. In addition to the cross walls, the longitudinal walls were strengthened by occasional internal piers 2 bricks wide and of 3ft. projection. The total height of the walls from the ground to the eaves was 36ft.; this included a vaulted basement 5ft. high having a granite facing. The thickness of basement wall was 2ft., and the outer brick walls above were 2 bricks thick, supporting a deep corbelled brick cornice. The height, from ground floor to the tie beams of roof, was about 24ft. The external walls had semicircular headed windows about 5ft. wide and recessed—the intermediate solids being from 8ft. to 9ft. wide—and deep horizontal wall spaces remained above the windows. The building was covered with queen-post roof trusses placed about 8ft. apart, having heavy tie-beams let into the walls and resting on continuous wall plates. These wall plates and the pole plates of the roof had been a little loosened by the earthquake. This Mint contained heavy tanks of water for cleaning and separating the ore, and the earthquake shock had been

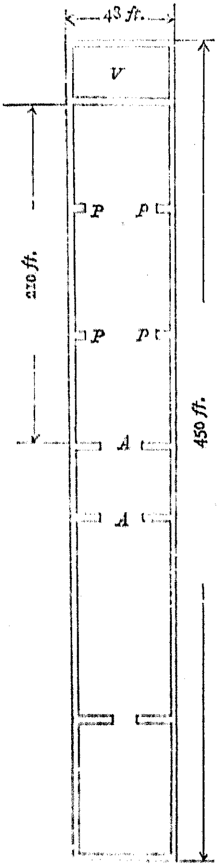


Fig. 54.

sufficient to cause overflow though they were only partially filled at the time.

In the Forge there were six high chimneys. The largest was a wide thick chimney 120ft. high with a light cap. This was the only chimney *fired* at the time of the earthquake, the others being cold, and it was cracked right down, whereas the remainder, though of weaker construction, were uninjured. The large Boiler Room, supporting a heavy water tank bolted to the brickwork, was uninjured, not even the tiles falling. The edge tiles had been nailed to the roof, which is not always customary.

The Rolling Room was a large brick building about 450ft. long covered with a heavy queen-post roof. In the walls of this building diagonal cracks were observed extending from below the roof trusses. The bricks between the roof beams were also much loosened. A lean-to roof adjoining this building had opened, and the bricks at its connection with the wall were loosened.

The buildings of the Osaka Arsenal were next inspected. They consisted of numerous brick structures representing a combined area of about 6,200 *tsubo*. They were situated on one side of the river with deep moats on their other side, the site forming a sort of large promontory. The Arsenal Office, designed by Mr. Yoshii, Architect,—a high two story building with a basement—was uninjured. The other principal buildings consisted of large workshops constructed with enormously thick walls, the commonest class having walls 3½ bricks thick with additional strengthening piers. A workshop for the manufacture of cannon supports had walls measuring 3ft. 6 inches thick through the piers, with recessed walls and semi-circular headed windows. It had a thick internal wall dividing it longitudinally. Both the inner and outer walls were recessed above for *travellers*. The whole was covered with a double queen-post roof. A few old cracks were perceptible in the plinth, owing to settlement, but there was no injury that could be attributed to the earthquake.

Another large workshop built of brick with granite quoins, having a central portion three stories high, used as offices, and measuring about 40ft. to the eaves, showed no fracture or crack, notwithstanding its irregular height and the unequal weight of the high and low portions. Enquiries addressed to the engineers in charge about the construction of these workshops elicited the information that they had very deep brick footings formed of steps with comparatively slight projection (see Fig. 55). Below this had been laid two courses of hard stone placed alternately longitudinally and cross-ways, with spaces between filled with concrete. These rested on piles 20ft. and 26ft. long driven 3ft. 6″ apart into the red clay and continually under water. No concrete was used between the stones and the pile heads. The mortar employed for the brick-work was composed of 1 part cement, 1½ parts lime, and 5 parts sand. For the concrete between the footing stones 1 part cement, 1 part lime, and 6 parts of brokens stones had been used. The cement was of different brands, tested to bear a breaking strain of 300lbs. to the square inch in a neat state. The mortar had been mixed in mortar mills.

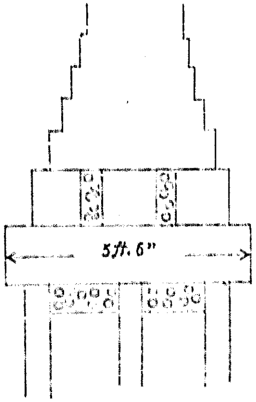


Fig. 55.

The compound contained about 14 high chimneys in all, and portions of four of these had fallen, some of the remaining ones being slightly cracked. About 21ft. length of one large chimney had opened out and fallen in two halves in different directions North, and South, the falling portions damaging the roofs of the adjacent workshops. The tops of three other chimneys had fallen. Various proportions of ingredients had been used for the mortar of these chimneys, viz., 1 part cement, $1\frac{1}{2}$ parts lime, and 3 parts sand; 1 part cement, $2\frac{1}{2}$ parts lime, and $7\frac{1}{2}$ parts sand; and 1 part cement, 4 parts lime, with 4 parts sand.

Conclusions arrived at after the inspection of these principal Government buildings were as follow:—Making allowance for certain evidence of amateur construction (unavoidable in the early days to which they belong, when architectural works were entrusted to mechanical engineers and others having little knowledge of architectural building), these structures had been solidly and carefully built, with a maxmium of strength in the foundations, walls, and other important parts. Their situation, close to the river bed, which had marked the line of greatest seismic disturbance, and the fact that their chimneys had fallen and the water in tanks had been thrown out, together with the report of those present at the time of the earthquake as to its alarming severity, seemed to show that they had been shaken with the same degree of violence as had occasioned serious injury to other brick buildings in Osaka. They had, however, only received very trivial damages. Whatever, then, may be the arguments against excessive stiffness and solidity when building with a flexible material like wood (and the writer is strongly inclined to the opinion that even in timber structures solidity and stiffness count for a great deal, as repeatedly demonstrated in the precedent pages), in brick and stone buildings, indisputably, extra thickness of walls and general massiveness of construction was greatly advantageous from a seismological point of view. Such a statement would seem almost superfluous, were it not for the often-repeated argument that, because seismic forces are irresistable, the idea of building strongly in order to counteract their violence must be an erroneous one, and that the principle of making a building and the different parts of a building yield and "give" is the more correct principle to be followed in practice. Without doubt the recent earthquake had shown that the connection of different materials and of very different masses of the same material in one structure were causes of weakness and injury during earthquake. This was even exemplified in the solid building last referred to, in which timbers had loosened bricks and caused cracks in the walls; but the writer saw no satisfactory compromise between *strengthened connection* and *complete isolation*. *Partial isolation*, or *looseness of connection*, had, in all cases, proved most detrimental. If an annex or a tower could not be isolated from the main structure so considerably that in their oscillating swing the two had no chance of colliding, then the more strongly they were tied and connected together the less was the damage likely to be occasioned. In the same way, if timber floors and roofs could not be distantly isolated from the brick walls, then it had been proved that they were less injurious to such brick walls when stiffly framed to one another and strongly united to the walls than when loosely penetrating the walls and allowed to move independently in their different parts.

The existence of careful drawings and detailed specifications; the use of the best skilled superintendence available and of the best materials procurable; and the execution by day work or small contracts for the different trades instead of by general contract; were all points which distinguished these Government buildings from the greater number of the commercial buildings among which serious accidents had occurred. Even among the manufacturing buildings themselves (necessarily more economically and hastily built than the principal Government erections), a scale of growing audacity and of decreasing care and precaution in construction could be easily traced. We find the first Cotton Spining Mill, at Sangenya, built under the ægis of the Mitsui Company with the greatest care and solidity, using skilled superintendence, and ungrudging any necessary expense. This is followed by the other Mills borrowing from the Sangenya its arrangements, but thinning the walls, though at the same time increasing the spans; substituting wooden floors for iron ones, and wooden tile-covered roofs for light iron coverings; widening windows and decreasing piers; dispensing with cement; mixing mortar by hand instead of by machinery; and employing the services of assistants as super-intendents. And lastly, we find the general contract system introduced, the contractors being mostly speculators of no experience, possessing no machinery, plant, or special facilities, and the machinist in charge of the Mill being the only supervising "architect."

Surely such results pointed to the necessity of strict building regulations and some governmental control which should ensure at least that important works were only undertaken by properly certificated experts. Commercial and manufacturing buildings could not be made monumental, and economy became a most important factor in their construction, but it was the expert alone who knew how far economy could be carried without endangering stability, and the safety and lives of inmates. One of the lessons learnt from this severe earthquake was that the constant presence of trained and experienced supervision in *small matters of constructive detail*, such as mortar mixing, soaking bricks, bricklaying, grouting, squaring beds and backs of ashlars, bonding wood-work into walls, &c., &c., was quite as necessary as was professional knowledge in the preparing of working drawings and specifications. It was too often of late the practice to obtain general drawings and entrust any one to carry out the work.

In the matter of Factory chimneys, and also the ordinary chimneys of buildings, the best and strongest class of structures seemed to have fared scarcely any better than those of inferior construction. With regard to very high chimneys of brick, certain improvements might be possible in increasing their thickness, building the brickwork in neat cement, and introducing iron bands and straps, but they would probably always be a source of danger during severe earthquakes. The substitution of iron plates in place of brickwork appeared to be the most practicable solution. For the ordinary brick and stone chimneys of buildings projecting above the roof and eaves it seemed also advisable to substitute light stacks of wrought iron plate firmly screwed to their brick stumps. For the safety of the woodwork of the roof it might be necessary to carry the brick stacks just above the roof line, commencing the ironwork above the lead flashing; but if double iron flues were used filled between with some non-conducting substance, or even with an air space, there seemed no reason why the ironwork should not be carried down through the roof timbers to the level of the highest ceiling. It appears almost needless to remark that complete isolation of brick chimney stacks from the roofing which they penetrated was impracticable in building, and the experience from isolated factory chimneys tended to show that such a treatment, even if possible of execution, would by no means be effective.

It remains to allude to one other building in the city of Osaka which was barely completed, viz.,—the Post and Telegraph Offices. This was a large brick and stone building in the Palladian style, having four corner pavilions of three stories and the remainder being of two stories in height (see Fig. 56). It had a large central or office hall measuring about 40ft. by 70ft. surrounded by piers 2½ bricks thick and 2ft. 9″ wide, with round arches constructed in four half-brick rings. The floor above was carried by large wooden beams penetrating the walls over the crowns of the semicircular arches, and supported internally on two cast iron columns. The thicknesses of the lower walls were, at the corner pavilions 3½ bricks, and in the two-story portions 3 bricks thick, very thick mortar joints (nearly ⅝ inch) had been used, and the brickwork rough externally as well as internally being to receive plaster. The mortar had been composed of 4 parts of lime to 6 parts of granitic sand, and had been partly mixed by mortar mill and partly by hand. The windows were of medium size, being from 4ft. 6″ to 5ft. wide, with intermediate wall spaces from 7 to 8ft.

wide. The height of the two-story portion was 44ft. to the top of parapet, and the pavilions measured 62ft. to the top of parapet. The balusters of the parapet were of cast iron supporting coping stones. The building had a high stone-faced basement, and above stone columns at intervals supporting stone cornices. The foundations had been built upon concrete composed of lime, Osaka cement, puzzolana, broken bricks, and gravel, laid on large boulders which had been rammed into the natural sand. No piles were used.

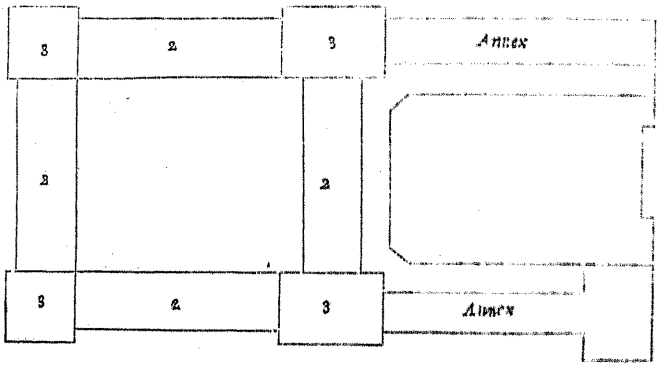


Fig. 56.

The earthquake had in no way damaged the main building though it was quite new and of varied heights. The low two-story annex, of cheaper and weaker construction, with walls only 1½ bricks thick at the top, had several cracks. These were observed at each end of a cross wall which carried a roof-truss—one being over a door arch in the corner, and one extending right down the solid wall (see Fig. 57).

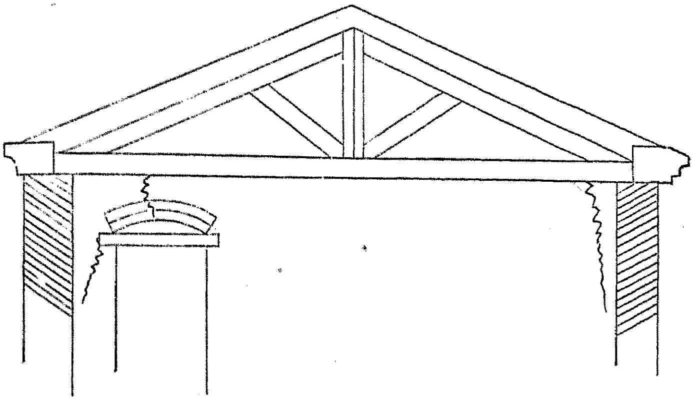


Fig. 57.

This completed the writer's examination of the principal buildings in the localities most seriously affected by the violent earthquake of October, 1891.