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THEORY OF EARTHQUAKE RESISTING DESIGN WITH A NOTE ON EARTHQUAKE RESISTING CONSTRUCTION IN BALUCHISTAN

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Fundamental Principles of Earthquake resisting construction.

The fundamental and basic characteristic of earthquake proof construction is the rigidity of the structure, *i.e.*, the various elements of the building are so rigidly connected to each other that in spite of the differences in their period due to a difference in their masses and location, they are forced to vibrate together in an earthquake shock. The non-synchronising action of the members of a non-rigid building is one reason for its destruction in a violent earthquake.

Again the rigidity of construction has a damping effect on the vibrations of the building. A rigid structure comes to rest quickly. There is, thus, no tendency for the amplitude of motion to increase under the influence of successive impulses.

Observations made by Dr. Suyehiro (late Director, Research Institute Imperial University of Tokyo) indicate that "a rigid building moves nearly the same as the surrounding ground and is insensible to those vibrations of the ground having very short periods which are hnown to cause fairly intense acceleration. A non-rigid building moves with its own period ; the amplitude of the maximum motion at the top being two to three times that of the basement floor. The motion of a building of a medium rigidity is intermediate between these."[1]

Dr. Majima and a few other engineers of Japan and America are exponents of " Flexibility " as opposed to " Rigidity." They advocate the use of elastic columns in the lower story so as to allow the building to oscillate to and fro for an inch or two without the internal stresses exceeding the safe elastic limits. This theory has found very little favour with the majority of engineers and architects.

The force of the earthquake, unlike wind pressure, is not against the face of the building but is proportional to its mass. Lightness should, therefore, be regarded as an essential feature of proper design for resistance to earthquake.

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[1] Proceedings, American Society of Civil Engineers, Part 2, May 1932.

Experience in earthquake damage indicates that the longer the natural period of vibration of a building, the greater is its susceptibility to earthquake shock and that the natural period of a building decreases if its rigidity is increased. "Thus it will be seen," says Dr. Suyehiro, "that, in buildings similarly constructed and of nearly the same size, those having a shorter natural period have greater rigidity and more damping against vibration than those having a longer period. In other words, the former have more resistance against earthquake forces than the latter, provided the natural period of the building does not synchronize with that of the earthquake." [2]

This correlation between the period and strength can be mathematically demonstrated in the case of a beam :

$$\text{Thus } t \propto \frac{1}{I},$$

$$f \propto \frac{1}{I}, \text{ and}$$

$$d \propto \frac{1}{I}$$

where it is the period of transverse vibration of a beam.

I is its moment of inertia, and

f & d represent the induced stress and deflection respectively.

Thus shorter the period (*i.e.*, the smaller the value of t) the lower are the values of induced stresses and the deflection and therefore the stronger the structure.

Note only should the building have a short period of vibration but it should also be capable of maintaining that period. It has been observed that after a building has cracked due to the failure of the walls or of weak bracings by the preliminary shock, the period of the building is increased. It thus becomes less safe against weaker after-shocks.

Since the earthquake force is in the mass of the building wherever it is located, it is easy to see that the lower the centre of gravity of the building the less would be the bending moments induced in its vertical members under the action of the earthquake force and consequently the safer would the structure be, as a whole.

Great care should, therefore, be taken to avoid a top heavy design and to make the upper portion of a building as light as is consistent with its safety and its utility. The top heavy buildings of inferior construction suffered heavily in the Italian earthquake of 1930 although the buildings were located on the hard ground and rock.

[2] Proceedings, American Socicty of Civil Engineers, Part 2, May, 1932.

The safe height of a building is limited by the tensile resistance and elasticity of the building materials and the increase in the period of a building with height.

Thus the Japanese regulations prescribe that the total height of wood frame and brick-buildings should not exceed 50′, and that of steel frame and reinforced concrete buildings should not be more than 100 ft.

"With the present lack of data," says Mr. Freeman, "regarding the accumulative effect of oscillations in extremely tall structures, it is highly desirable to limit the height of the buildings to 100 ft. above the street level or about 8 ordinary stories in regions particularly liable to severe earthquakes." [1]

Experiments by Prof. Hall on the natural periods of a number of typical buildings in San Francisco indicated that almost in all cases the natural period of a building increased with its height. A tall building would, consequently, be more liable to damage in a destructive earthquake.

In this connection Mr. Robins Fleming says in his treatise on "Wind tresses in buildings"(published 1931) as follows :—

" It is a matter of conjecture as to what would happen in New York City in case of an earthquake. The 30, 40, 50-story buildings have not been designed with earthquake stresses in view. Moreover it is practically impossible to do so for shocks greater than VI or VII of the Rossi-Forel Scale."

The problem of the "skyscraper" is fortunately not an Indian problem at present as the height of the tallest buildings in the foremost cities of India rarely exceeds 100′.

Materials suitable for earthquake resisting construction.

A steel-frame structure with rigid connections between its horizontal and vertical members and with its walls, partitions and floors of reinforced concrete stands highest as regards its resistance to severe earthquakes. Mr Hadley found that out of 16 steel-framed buildings in Tokyo in 1923, the six that remained undamaged embodied "an adequate amount of reinforced concrete wall construction which so stiffened and braced them that they suffered no damage whatsoever." Brick-filler walls on account of the low tensile strength and elasticity of the material are inferior to walls of reinforced concrete but can be designed to withstand earthquakes of moderate intensity.

A steel-frame is to be preferred to that of a reinforced concrete for the following reasons :—

(*a*) For equal strength, steel-frame work is lighter.

[1] *Earthquake Damage and Earthquake Insurance* (published Dec. 1931) by J. R. Freeman.

(*b*) Stresses in a steel structure can be more accurately determined.

(*c*) Strength of steel in shear is almost equal to its strength in compression. This is not the case with reinforced concrete.

(*d*) Steel has a higher modulus of elasticity and is more suited to reversal of stresses.

With a proper design and careful execution reinforced concrete ranks second best for its use in earthquake proof buildings of moderate height. It has been successfully tried " at the bar " of very severe earthquakes in San Francisco in 1906 and in Tokyo in 1923. It failed only when it lacked strength and rigidity due to inadequate design or poor quality of workmanship.

" Wooden buildings," to quote Mr. Hadley,[1] " when adequately braced, withstood the Tokyo earthquake without damage ; when inadequately braced, they collapsed. Their light weight is, of course, an excellent quality for the resistance of forces that are a function of the weight, although the likelihood of fires following a severe earthquake makes their use hazardous in closely built up districts."

At Santa Barbara (America) the earthquake of 1925 caused only a damage of $2\frac{1}{2}$ % of the total value of the wooden buildings. Wood-frame buildings at Dharamsala stood the Kangra earthquake of 1905 so successfully that ever since all Government buildings in that locality have been built with this material. It may, however, be noted that wooden buildings do not fare so well on soft ground. Under such circumstances foundations should be carefully designed. The difference in damage depends on the quality of design and workmanship.

Brick or stone buildings when built with strong cement mortar and laid with a good bond offer a considerable resistance to earthquake forces if their height does not exceed 40 to 50 feet.

Ordinary brick-work laid in lime mortar, lime mortar rubble, *adobe* and *kacha* brick-work are all vulnerable and are not trustworthy materials for use in localities subject to destructive earthquakes.

Allowances for earthquake force in building design.

At a distant seismograph it is only the horizontal wave motion that is recorded but near the epicentre the vertical motion is equally prominent. It is the horizontal component of earthquake motion, however, which causes most of the destruction ; the vertical component of the motion may be neglected since even if the acceleration due to this were equal to that due to gravity, the stresses in the members of the building would only be doubled. These increased stresses are amply covered by the factors of safety usually allowed for in the design.

[1] Bulletin of Seismological Society of America for March, 1924.

It is unfortunate that very little reliable data is available regarding the acceleration due to the horizontal component of earthquake motion. This is due to the following reasons :—

(*a*) A seismograph has very rarely been located in a region subject to a destructive earthquake. Wherever there has been one, it has instantly been thrown out of operation on account of the extreme delicacy of the ordinary instrument which enables it to record distant earthquakes. Considering the last earthquake in Baluchistan the nearest seismograph is at Colaba (Bombay). Strong motion seismographs and accelerographs are very recent inventions and are still being perfected.

(*b*) On account of certain defects in the design of the ordinary seismographs the acceleration derived from the seismograms is not reliable.

(*c*) Dr. Suyehiro's observations indicate that the maximum acceleration in an earthquake does not result from the main earthquake motion but is given by secondary motion with comparatively small amplitude but of short period. This secondary motion which is probably due to 'habitual' motion of the ground is masked by the main motion on a seismogram. Thus only a properly designed accelerograph can give us the correct value of the maximum acceleration.

All the information regarding the magnitude of acceleration has usually been obtained by the following methods :

(*i*) From the overturning of walls, pillars and monuments. This, on account of the inherent defect in the method is unreliable.

(*ii*) From the ordinary seismograms by assuming the earthquake motion to be harmonic (which it is not). This, as has already been stated, is not capable of giving correct results.

(*iii*) Calculation of acceleration from the record of distant seismograph by use of certain formulæ such as :—

1. $\frac{a}{a_o} = \sqrt{\frac{d_o}{d}}$

2. $t^2 = t_o^2 - \cdot 16\,(d_o - d)$

3. $A = a\left(\frac{2\pi}{T}\right)^2$ where A is the acceleration required at any place.

Where a is the amplitude of motion at any place.
a_o is the amplitude at any place where a seismograph is located and which is therefore known.
t and t_o are similarly the periods in seconds at these two places.
d and d_o are distances in miles of these places from the epicentre.
It may be noted that no direct or indirect evidence is available to show that these formulæ are correct.

From the above it is, therefore, clear that the values of the seismic factor (*i.e.*, the ratio of the acceleration due to the quake to that due to gravity) prescribed by various codes are, at best, guesses tempered by judgment. The only indirect evidence available so far is that certain buildings in Tokyo designed for an acceleration of about ·1g resisted the earthquake of 1923 fairly well.

At this stage it is necessary to clear a common misunderstanding caused by an unfortunate statement made by the Earthquake Committee of the American Society of Civil Engineers in 1907 that "sufficient evidence is at hand to warrant the statement that a building designed with a proper system of bracing to withstand wind at a pressure of 30 lbs. per sq. ft. will resist safely the stresses caused by a shock of an intensity equal to that of the recent earthquake in California."[1] A little calculation shows that the use of wind pressure criterion is not only absurd but is a very unsafe basis for earthquake resisting design.

Before fixing the values of the seismic factors to be allowed for in the design of earthquake resisting structures in India it is necessary to study the frequency and the intensity of the earthquakes in the different parts of this country.

Plate No. I shows that India can roughly be divided into four regions of varying degrees of seismicity :—

(*i*) Areas subject to violent earthquakes comprising certain parts of Assam, Arakan, Bengal, area round Kangra and Mussoorie.

(*ii*) Areas subject to strong earthquakes. They include parts of the Indo-Gangetic plain at the foot of the hills, and the extra peninsular area, (*i. e.*, the mountainous region which borders India to the west-north and east including Baluchistan and the hill tracts of Burma).

(*iii*) Areas of weak earthquake. The southern and south-western parts of the Indo-Gangetic plain and Rajputana.

(*iv*) Areas of rare earthquakes. This includes the Deccan Peninsula and Ceylon.

This map[2] also shows the limits of the areas over which the principal Indian earthquakes in the 19th century were felt.

The difference in seismicity of the different parts of India is the direct result of the geological structure of the peninsula and extra-peninsula.

"Peninsular India," says Mr. Wadia in *Geology of India* is a segment of the earth's outer shell that is composed in great part of generally horizontally reposing rock beds that stand firm and immovable upon a deep-seated foundation and that have, for an immense number

[1] Transactions of the Am. Soc. of C. E., Vol. LIX, December, 1907, p. 234.

[2] This map is based on the information given in a map in *Erdbe benkunde*, by A. Sieberg (published 1923) and in Map No. 3 by R. Oldham in Vol. XXIX of the Memoirs of Geological Survey of India (published 1899).

of ages remained so impassive and undisturbed amid all revolutions that have again and again changed the face of the earth.... The extra-peninsula, on the contrary, is a portion of what appears to have been a comparatively weak and flexible portion of the crust that has undergone a great deal of crustal deformation. Rock-folds, faults, thrust planes, and other evidences of movements within the earth are observed in this region on an extensive scale, and they point to its being a portion of the earth that has undergone at a late geological epoch, an enormous amount of compression and upheaval."

It is for this reason that "few earthquakes have visited the peninsula since historic times ; but those that have shaken the extra-peninsula form a long catalogue. It is a well authenticated generalisation that the majority of the Indian earthquakes have originated from the great plains of India or from their peripheral tracts." [1]

From the above considerations the following values of the seismic factors are recommended :—

Class of Building.	*Values of the seismic factor.*			
	Areas of violent earthquakes.	Areas of strong earthquakes.	Areas of weak earthquakes.	Areas of rare earthquakes.
A Class	·15g	·10g	·05g	nil
B ,,	·10g	·075g	nil	nil

Note.—'A' class buildings for this purpose include all monumental buildings and buildings above 50 ft. height.

'B' class buildings include buildings below 50 ft. height.

Although there is abundant evidence to show that the horizontal acceleration in the epicentral regions is much more than ·15g yet one must not overlook the important fact that earthquakes come once or at the most twice in the life of any building. A high value of the seismic factor would, therefore, mean extravagance in the case of Government buildings and a requirement "greater than the traffic can bear" in the case of private buildings.

[1] *Geology of India*, by Wadia, p. 28.

Besides the above there are other reasons for adopting a lower value of the acceleration for design. They are outlined below :—

(*a*) Brevity of the application of the earthquake's extreme force.

The usual period of earthquake vibration varies from 1·0 second to 1·5 seconds. The force in one direction is applied within $\frac{1}{4}$th of the period and varies from a maximum at one end to zero at the other. The length of application of the maximum force is of the order of an extremely small fraction of a second. In this brief interval there is very little chance for the estimated deformations to take place in the structure and for the assumed stresses to be distributed through its various parts.

(*b*) Irregularity of the earthquake motion.

A number of seismograms show that the motion of a particle is mainly in an elliptical path and not back and forth in nearly a straight line, as is assumed in the common method of computing earthquake stress in a structure on the basis of harmonic motion and an acceleration of ·1g.

The irregularity of the path also indicates noteworthy absence of uniform periods of oscillation, such as might build up great amplitude in a tall structure and cause greater strain. Thus, so far as they go, this irregular path indicates that the errors of the ordinary method of estimating acceleration and stress are perhaps on the safe side.[1]

(*c*) The possibility of greater earthquake violence than allowed for is covered by the factor of safety provided. Some engineers are in favour of using a seismic factor of ·3g to ·4g with working stresses double the ordinary unit stresses, or equal to the ultimate stress of the material.

Current practice regarding a suitable value of the seismic factor in other countries such as Japan, Italy and America will be indicated by the following quotations :—

1. "It seems to me that a building properly designed to provide against a horizontal acceleration of, say, 0·15 of the gravitational acceleration, with a reasonable factor of safety, would safely withstand destructive earthquakes of the intensity of that of 1923, which is one of the most severe in the record of seismic history. Indeed, our own building code provides for a horizontal acceleration of ·1g, but some engineers are not satisfied with this seismic factor and voluntarily increase it." (Lectures in America by Dr. K. Suyehiro, p. 56, Proc. of Am. Soc. of C. E., Vol. 58, May 1932.)

[1] Page 843, *Earthquake Damage and Earthquake Insurance* by J. R. Freeman.

2. Resistance to horizontal force that may be caused by seismic acceleration applied to the masses of the various parts, must be provided, both in longitudinal and transverse directions, having a magnitude in relation to the total weight of structure above floor level of :—

1 to 8 for basement,

1 to 8 for first floor,

1 to 6 for upper floors.

In buildings more than 10 or 12 metres (33 to 40 ft.) in height, this ratio must be 1 to 6 for all floors (Article 31 of the Royal Decree issued in Italy on April 3, 1930).

3. In the new building codes now in process of development in California by the Municipal Committees, the seismic factor is made 10% for soft ground, capable of bearing two tons or less per sq. foot, and 7·5 per cent. for the hardest ground. Under the the tentative PALO ALTO Code the seismic ratio is 20% for soft ground, 10% for the hardest ground and 15 per cent. for intermediate ground (Freeman in *Earthquake Damage and Earthquake Insurance*, p. 795).

Specifications for earthquake proof construction.

Experience shows that the amplitude of earthquake motion in soft ground, deep alluvial deposits, made land, marshy soil and scree-covered or gravel terraces is considerably more than on hard compact ground or rock. Therefore the damage done by destructive earthquakes to ordinary buildings in such localities is much greater. On the other hand, a rigid building on soft ground behaves in quite a different manner. On account of its inertia, its movement is much smaller than that of the adjacent ground. Instead of moving horizontally with the ground it has a rocking motion similar to that of a pebble on the surface of gelatine.

While selecting a suitable site for a building preference should, however, be given to solid rock or compact soil. Alluvial flats, gravel terraces and soils of which the upper parts consist of loose materials, should be avoided, if possible. Buildings required to be erected in such localities should be provided with specially designed foundations.

The most dangerous of all sites is that at the periphery of an alluvial earth basin where it borders on a rock or more rigid ground such as at the foot of a hill. At such a place the phenomena of the interference and building up of the earthquake oscillations is particularly noticeable and ground has been observed to hump up considerably.

The shape or the ground plan of a building is of considerable importance as it has been observed that the irregularity of the shape has a great influence in increasing the amount of damage to a building in an earthquake. The ground plan of a building should, therefore, be of a

closed type. A square or a rectangular plan is much to be preferred to an irregularly-shaped layout. Compactness and uniformity of height of the various parts of a building afford a good opportunity for symmetrical bracing and thus help in unifying the periods of the oscillations of its various parts.

The building should be laid out in such a way that it offers the greatest resistance to the earthquake. This object can be attained by placing its length in the prevailing direction of the earthquake shocks. Such a layout also simplifies the problem of bracing. On an area near a well-defined fault the building should, therefore, be set out with its length at right angles to that of the fault. In a locality subject to destructive earthquakes where there are no well marked faults, the earthquakes may be expected from any direction as statistics indicate that no two earthquakes have originated from precisely the same location of the epicentre. It would, thus, be apparent that a fairly square shape of a building is the only remedy in such a case.

Firm and unyielding foundations are particularly essential for earthquake resisting construction. It has been observed that the amplitude of the vibrations of short periods decreases rapidly with the depth underground but this effect is not so marked with slow vibrations. Deep foundations are, therefore, more advantageous in the case of low buildings, with a short natural period of vibration than with tall buildings with longer periods.

On rigid ground or rock, continuous well spread foundations would do very well. Pier and light footings should be avoided. Tall buildings erected on a compact soil may be provided with a deep pile foundation.

For tall buildings on loose soil or soft ground a strongly reinforced concrete mat foundation is the best. For buildings of one or two stories a solid slab of lime concrete with a thickness of two to four feet depending on the loads to be carried, would be a cheaper and a very effective arrangement. If isolated footings are provided they should be connected to each other by steel or reinforced concrete ties as otherwise the uneven settlement in earthquake would lead to dislocations and ultimate failure of the foundations. Continuous slab reinforced concrete foundations are to be preferred to isolated spread footings on deep pilings.

The framework should be designed with an ample factor of safety to withstand not only the static vertical forces due to dead and live loads, but also the horizontal dynamic forces due to the earthquake. The allowance for the seismic force depends upon the locality. As the wind stresses and earthquake forces do not affect the building at one and the same time, the greater of the two should only be figured for design.

The framework should be made as rigid as possible by the use of large gusset plates connecting the steel columns to the floor beams and by providing vertical diagonal bracing. Where this is impracticable, on

account of wall openings the necessary rigidity can be obtained by the use of knee braces or portal bracings. Rivets in tension should be avoided. They should, preferably, be in shear wherever possible.

In a wooden framework diagonal bracing is equally essential. The pillars should extend the entire height of the building (if possible) to avoid joints. In place of the ordinary mortise and tenon joints, iron strips and bolts should be used in the joints of all structural members.

It is necessary to emphasize the importance of diagonal bracing. It eliminates the bending moments in columns, increases the rigidity of the structure and has a damping influence on the vibrations. In a rectangular frame without the diagonal bracing the natural period of the building is larger and many oscillations take place before the structure comes to rest. In such a case the successive impulses of the earthquake would tend to build up large amplitudes of motion which are disastrous.

The most essential requisite for a strong wall is its homogeneity of construction. Reinforced concrete on account of its monolithic construction is the ideal material for walls.

Walls of ordinary residential buildings should be built with bricks and small sized stone blocks laid with good bond in cement mortar. The height of such buildings should not exceed 50′.

Cross walls strongly connected to the main walls add considerably to the resistance of a building to earthquake. The length of walls not strengthened by buttresses or cross walls should not exceed 30′. Such walls when built with brick or stone blocks should have a minimum thickness of 1′-6″ for lengths up to 20′ and 1′-9″ for lengths from 20 ft. to 30 ft. Walls bearing roof loads should have a minimum thickness of $13\frac{1}{2}$″.

Exterior walls if built of reinforced concrete, should be provided with diagonal rod reinforcement. In Japan such walls are built with a minimum thickness of 8″. Partition walls should have a minimum thickness of 5″.

Brick or stone walls usually crack at the corners of a building and at the junction of the walls and the roof. The corners should, therefore, be adequately reinforced. To strengthen the junction of the roof and the walls the roof beams or slab should be secured to a framework of steel beams fixed on the walls or to a band of reinforced concrete running at the base of the roof.

The doors and windows of a building should be carefully planned as they materially affect its resistance to earthquakes. Greatly increased damage is caused by unsymmetrical openings. Long verandahs should be avoided.

Doors and windows should be as few as possible, and the doors should open outwards. The use of arches for the wall openings should be avoided. Reinforced concrete or steel beam lintels should be provided instead.

In reinforced concrete walls the corners of wall openings should be reinforced diagonally to prevent cracks due to shrinkage and due to stresses caused by lateral external forces.

Floors and roofs should be secured to the walls or the steel or concrete framework as rigidly as possible. A rigid floor or roof serves to distribute the lateral forces over the entire building.

Imperfect joints between columns and floor beams should be avoided.

A reinforced concrete roof or floor slab should be reinforced not only in two directions but also diagonally.

Use of jack arches for roofing is not considered safe unless the steel joints are secured transversely by cramp or cross beams.

Roof trusses should be strengthened by sway bracing. Roof covering should be as light as possible and should be carefully fixed to the frame. Use of heavy tiles in roofing is prohibited. Asbestos tiles on account of their lightness and resistance to heat may be used, provided they are firmly anchored to the battens.

In allowing for the live loads in designs of floors and roofs for earthquake resistance it is desirable to assume loads much lighter than those allowed for in the design of floor beams for strength. Thus for residential buildings, offices, hospitals and hotels a load of 10 lbs. per sq. ft. is ample. For stores, warehouses, theatres and schools a figure of 10 to 50 lbs. per sq. ft. should be taken according to circumstances. An unnecessarily high figure of live load would necessitate heavy floor members and would thus result in a top heavy structure which is dangerous.

Unnecessary ornamentation should be carefully avoided as it not only increases the weight of the structure but is also liable to break off the walls and cause injury to people below. Thus heavy cornices and projecting balconies are dangerous unless they are adequately designed and constructed under careful supervision. Stucco ornamentation and hollow tiles as facing or backing should be prohibited unless they are securely anchored to the walls.

Parapets should not be higher than 3′ unless they are properly reinforced and rigidly connected to the reinforced concrete roof, otherwise they are very likely to fall off in a severe earthquake on the heads of the people in the street.

Chimneys are the weakest part of a building as they are most susceptible to earth tremors. They should be avoided wherever it is possible. Steel plate or reinforced concrete are the best materials for chimneys in seismic regions. Use of galvanised iron for chimneys of residential houses is recommended.

Brick chimneys should be kept as low as possible and should be strengthened by steel sections embedded in the joints of the brickwork. Too much corbelling on the top should be avoided.

No piping or electrical conduit should be set into the building structure. The mains should be laid in a trench underground to prevent injury during an earthquake. Electric lights should be fixed to the ceiling or should have stiff suspension.

A brief account of the earthquake of August 1931 in Baluchistan.

The earthquake consisted of two main shocks and a large number of after-shocks of varying intensity which continued for some months. The latter gradually decreased in their severity and frequency.

The first main shock was experienced at about 3 a. m. on Tuesday the 25th August and had probably originated in the neighbourhood of Sharigh, a station on the Harnai route of the Sibi-Quetta Section of the North Western Railway. According to Mr. West of the Geological Survey of India " This shock just reached an intensity of about 8 on the Rossi-Forel Scale. The shock was probably a shallow one, and the effects of it rapidly diminished away from the epicentre. It was felt over an area roughly triangular in shape, the apices being at Chaman on the west, a little east of Kila Saifulla on the east and at Mehar in the south." At Quetta and Ziarat the shock was rather severe. At Mach it was clearly felt but was rather mild.

As a result of this shock most of the *kacha* buildings of the small bazaar at Sharigh were completely ruined. The station buildings built of *pucca* bricks in mud mortar was badly cracked. Most of the staff quarters including the dispensary were more or less seriously damaged and had to be rebuilt. At Quetta this shock did not cause much damage but was responsible for the cracking of a number of buildings at Ziarat.

The worst was yet to come. On the 27th evening at about 8-54 p.m. there was experienced at Mach the second main stock, probably the severest of all shocks within the living memory of the people of Baluchistan. The epicentre of this shock which was felt over Baluchistan, Sind and the south-western part of the Punjab and western part of Rajputana was located near Mach. It attained an intensity a little above No. 8 on the Rossi-Forel Scale. This shock lasted for about a minute and a half. Some people have reasons to think that the direction of the shock changed from North-South to an East-West or S. E.-N. W. direction. At Sharigh and Ziarat this shock was as severe as the first main shock but at Quetta and Mach this was considerably severer than the first one. The map in Plate No. II indicates the isoseismals or the lines of equal intensity of shock on the Rossi Forel Scale.[1] It would be clear from this that this

[1] This map is based on the information supplied by the Director of the Geological Survey of India.

earthquake was not as severe as the Assam earthquake of July 1930; was less severe than the Kangra earthquake of April 1905 and very much less in violence than the great Assam earthquake of June 1897.

This shock caused serious damage at Mach and in the surrounding country within a short distance of Mach and in the alluvial tract at the foot of the hills to the south-west of the Sibi. At Mach the whole bazaar and almost all the railway buildings were razed to the ground. A few units of the menial quarters and the Loco shed were the only buildings that were left standing. The new central jail at Mach suffered considerable damage. Its power house, however, came through the earthquake almost unscathed. The buildings in the jail area were badly cracked, their chimneys were overturned and their thin *purdah* walls collapsed.

Means of communication by telegraph and telephone, road and rail were all interrupted. The Sibi-Quetta Road was completely blocked at several places and at a number of places no trace of the road was left.

At Sharigh the railway water-supply was completely destroyed. The pipes were shattered and stripped of their screw joints at Mach. Here the masonry reservoir was badly cracked. The level of the water-table fell considerably at Dozan while the yield of the springs at Mach and in the Urak Valley on the north-east of Quetta and in the Karezes increased considerably.

Panir, a station twenty miles to the south of Mach was laid flat. At Quetta a number of buildings were seriously damaged and had to be dismantled. Considerable damage to life and property was done at the villages of Dhadar, Mushkaf, Sanni, Shoran and Gandawa. About a hundred lives were lost.

Numerous fissures appeared in the railway embankments and sides of cuttings. The track buckled at several places and a number of railway bridges were rendered unsafe for train operation. Heavy pieces of rock were dislodged in the Nari Gorge and a number of railway tunnels were slightly cracked. The total loss to the railway property was estimated at Rs. 23 lakhs.

This earthquake was not due to any volcanic disturbance but was of a tectonic origin, *i. e.*, due to a sudden rupture of a subterranean rock caused by subsidence of the earth crust.

Previous earthquakes in Baluchistan.

From a note compiled by Diwan Bahadur Jamiat Rai, C.I.E., which was published in the Baluchistan Gazette of 11-9-31, it appeatrs that "earthquakes are not uncommon in the greater part of Baluchistan except in Mekram, Kharan and Lasbela where they occur rarely." He gives a brief account of some 18 earthquakes between the years 1862 and 1909 but none of them were as violent as those of Kangra or Assam. Most of these shocks have been confined to an area within a radius of about 200 miles round about Mach and have a distinct relation to the geological structure of this locality.

From the above it would be clear that Northern Baluchistan has frequently been subject to strong earthquakes. The earthquake of 1931 exceeded all these in violence. It is, therefore, highly desirable that all Government buildings and buildings to which the public resort for recreation such as theatres, cinema halls and clubs should, at least, be built to withstand such earthquakes.

Structural lessons from the Baluchistan earthquake of 1931.

Most of the buildings in the locality where this earthquake was rather severe, consist of a single storey although a number of double storey buildings exist at Quetta and at a few other places. Wood is not easily available and is very costly. There are therefore no wood frame buildings. The vast majority of the buildings in the plains were built of sundried mud bricks laid in mud mortar, which on account of the low annual rainfall serve the purpose fairly well. In the hilly tracts most of the buildings were built of rough stone blocks laid in mud mortar. The roofs consisted of wooden beams, battens, *sirki* and mud. Buildings built of *pucca* bricks in mud mortar are very uncommon except at Quetta. There was not a single building specially designed to resist earthquakes although, as has been seen, Baluchistan is frequently visited by strong earthquakes. With such inferior construction, it is not, therefore, surprising that the earthquake, which was in no way of a very high intensity, played such havoc. The relative degree of damage in all cases, depended on the quality of the design and workmanship.

Thus at Mach most of the buildings in the bazar and the Railway Colony which had either stone walls or walls of *kacha* bricks were completely ruined. The workmanship was generally poor and the masonry work which could be described as "random rubble" lacked homogeneity and good bond.

Brick buildings for the jail staff at Mach and other brick buildings in general fared very much better. The outer walls of the jail quarters were 18" thick built of *pucca* bricks in mud, inside walls were of sundried bricks 13½" in thickness. The roofing consisted of light C. I. sheets carried on wooden purlins and trusses with a ceiling of mud plaster on wire mesh. In these buildings the half brick *purdah* walls fell down and the chimneys were overturned. These had to be rebuilt. There were cracks in the end walls at corners and at junctions of walls. These were all repairable. The jail power house and the railway engine shed with their walls of *pucca* brickwork in lime mortar buttressed at regular intervals and with roofing of C. I. sheets carried on steel trusses received no serious damage. Two blocks of menial's quarters at Mach built with *pucca* bricks in cement mortar withstood the shock successfully. One of these blocks had jack arch roofing and the other a C. I. sheet roof. It would thus appear that earthquake-resisting

construction can be secured with any material provided the buildings are constructed honestly and with good sense. For buildings of moderate height, however, the safest and most economical results can only be obtained with structural steel or reinforced concrete but for low buildings of one or two stories, walls of brickwork in cement mortar with roofs of reinforced concrete slabs would give adequate amount of protection against destructive earthquakes.

Chief Features of the Earthquake Resisting Staff Quarters in Baluchistan built by the N. W. R.

It seems desirable that before the structural features of the earthquake resisting quarters are described, the circumstances under which their designs were evolved should be briefly outlined.

The administration was faced at that time with a number of problems which demanded immediate solution. It was clear that all the staff who had been rendered homeless by the earthquake had to be housed as early as possible. The earthquake stresses had to be taken into account while designing these quarters. Rough estimates of earthquake proof houses indicated that they would be far too costly to be financially justified. A compromise had therefore to be made between perfect safety against earthquakes on the one hand and excessive cost on the other. The designs were, therefore, modified to be earthquake resisting. Even the modified designs would not secure the 4 % return, usually required, on the capital cost of these quarters. As the accommodation provided in these quarters could not be reduced, the only alternative left for reducing the cost was by the use of second-hand materials in stock. At that time the Railway was replacing iron rails by steel rails. Instead of auctioning these rails it was decided to utilise them for providing a framework for these quarters. On account of the excessive cost of wood, woodframe construction common on the Kangra Valley Railway could not be adopted. The chief features of the earthquake resisting construction in Baluchistan are mentioned below.

The framework consists of second-hand rails embedded at the lower end in the brickwork and anchored into the foundation concrete. The rails before embedment are coal-tarred or painted to prevent rust. The rail framework carries the trussed roof of rails which is connected to it as rigidly as possible. The framework divides the wall spaces into rectangular panels and besides adding greatly to the stability of the structure serves to localise the damage due to earthquakes. On account of the thin filler walls of brickwork it was not possible to provide any diagonal bracing. The stiffening afforded to the rectangular panels of the framework by the brick wall was considered adequate. The calculations given in Appendix I show that the framework is safe against a horizontal acceleration of 0·075 g. Plate No. III illustrates the rail framework.

The idea of providing main walls and partitions of reinforced concrete was given up on account of its relatively high cost and on account of the difficulty in arranging for skilled supervision during construction. It may be remembered that the reconstruction work had to be started simultaneously at several places.

As the roof load was carried by the framework the thickness of the brick walls in cement mortar was reduced to $4\frac{1}{2}$". The use of "celotex" for lining the walls to afford insulation against heat and cold was, at one time, contemplated but the idea had to be abandoned on account of its cost. Mud plaster on the inner and outer surface of walls provided a cheaper and a fairly effective remedy.

A half brick wall reduces the weight of the structure, and consequently the forces imposed on it by the earthquakes. The brick masonry is housed in the rail framework by cutting the bricks or by the use of specially moulded bricks or cement blocks. Tests described in Appendix II indicate that this arrangement affords sufficient shearing and flexural strength to the panel slab. It would be noticed that the brick panel is capable of withstanding an ultimate horizontal force of 350 lbs. per sq. ft.

Experience gained with the earthquake resisting construction indicates that a nine-inch wall is probably the absolute minimum for giving adequate protection against inclement weather.

Plate IV indicates the section of the walls and the foundations.

Doors and windows have been specified to open outwards to facilitate the rapid exit of the occupants during an earthquake and also to prevent their occupying too much of the useful room space. The horizontal rail frame has been placed just above the doors and windows and thus obviates the necessity of lintels.

As Baluchistan is subject to snowfall, a sloping roof was preferred to a flat roof. A slope of 1 in 6 would do in most cases though a slope of 1 in 3 gives a better appearance and is useful for shaking off snow in regions where the snowfall is heavy.

The roof truss (*see* Plate IV) is a simple triangular frame with the rails forming the principal rafters and steel rods forming the ties. The purlins have been dispensed with and a ceiling of half sawn second-hand sleepers is covered by C. I. sheeting rigidly secured to the rail rafters. The ceiling of wooden planks and painting of C. I. sheets with two coats of white lead gives adequate protection against heat and cold. Where the roof has a flat slope 2" to 3" of earth laid on the top of C. I. sheets further improves the insulation against the weather. Steel trusses have been used in buildings where the roof span exceeds 17'.

Instead of providing a brick chimney which would be susceptible to earthquakes it was decided to use reinforced concrete Hume pipes of 6" to 9" diameter. (*See* Plate No. V.) It was, at first, apprehended that under the influence of hot flue gases the concrete of the Hume pipes

would disintegrate but experiments arranged by the Hume Pipe Company in this connection left no room for doubt. The pipes are connected to each other by specially designed collars and are secured to the rail framework by suitable clamps.

Cost of the Earthquake Resisting Quarters.

The following types of quarters were designed for the varinus categories of the staff :—

(*a*) Q. 26 E for menials.

(*b*) Q. 27 E and Q. 28 E for junior subordinates.

(*c*) Q. 29 E, Q. 30 E and Q. 32 E for senior subordinates.

(*d*) Q. 39 E for assistant officers.

Plate No. VI indicates the accommodation provided in these types of quarters.

Photos Nos. 1 and 2 show the earth uake resisting buildings under construction.

The Table in Appendix III gives the actual cost figures for the various quarters; the cost per sq. ft. of the plinth-area of the earthquake resisting types, and the corresponding ordinary types, and the percentage increase in cost of the earthquake resisting construction over the ordinary method of construction. It would be noticed that, whereas in type Q. 26 E the earthquake construction is secured at an increased cost of 40 %, in the case of the quarters of senior subordinates the increase in cost is about 14 % and in the case of assistant officer's bungalow it is only 8 %. It would thus appear that in buildings of moderate size the earthquake resisting construction is not unduly expensive.

An analysis of the cost figures of these quarters indicates that the cost of the main items of work such as the foundations, roofing, framework etc., form almost a fixed percentage of the total cost of the building. Thus an average taken for types Q. 28 E and above gives the following results :—

(*i*) Foundations	16·4 °/₀	of the total cost
(*ii*) Brickwork in superstructure	12·0 °/₀	do.
(*iii*) Roofing	22·2 °/₀	do.
(*iv*) Framework	17·6 °/₀	do.
(*v*) Doors and windows	12·0 °/₀	do.
(*vi*) Other items	19·8 °/₀	do.

A glance at these figures would show that the roofing and the framework are the most expensive items and any effort at reducing the cost of these quarters should be mainly directed towards designing a cheaper roof or framework which would be capable of withstanding the earthquake force.

APPENDIX I.

Calculations of Earthquake stresses in frames of Earthquake Resisting quarters.

Type Q. 28 E. Plate No. VI

Test of central column in the wall between the bed and the living rooms.

The weight of roof is as follows :—

Corrugated iron sheets ..	..	3 lbs./sq. ft.
Half sawn U. S. sleepers ..	..	7 ,, ,,
Live load (assumed) ..	..	10 ,, ,,
Total	..	20 ,, ,,

The horizontal length of the rafter is approximately 8·5 ft. and therefore its sloping length $= 8{\cdot}5\sqrt{\frac{10}{3}}$

$= 8{\cdot}94$ ft.

The load carried by the central column is as follows :—

Wt. of roof $=8{\cdot}94\times7{\cdot}38\times20$ ..	=	1318·7 lbs.
Wt. of rafter $=8{\cdot}94\times20$ ..	=	178·8 ,,
Wt. of braces $=6{\cdot}5\times2\times20$	=	260·0 ,,
Wt. of brick-work panels $=5\times6{\cdot}5\times\frac{3}{8}\times140$	=	1706·25 ,,
Wt. of triangular $=6{\cdot}5^2\times\frac{1}{6}\times140\times\frac{3}{8}\times\frac{4}{3}$ panel	=	492·92 ,,
Wt. of column $=12{\cdot}17\times20$ ..	=	240·40 ,,
Total	=	4197·07 lbs.

There are two bents in the frame and the horizontal force exerted by earthquake on the frame will be assumed to be equally distributed between them.

Total vertical load on one bent is as follows for the upper storey :—

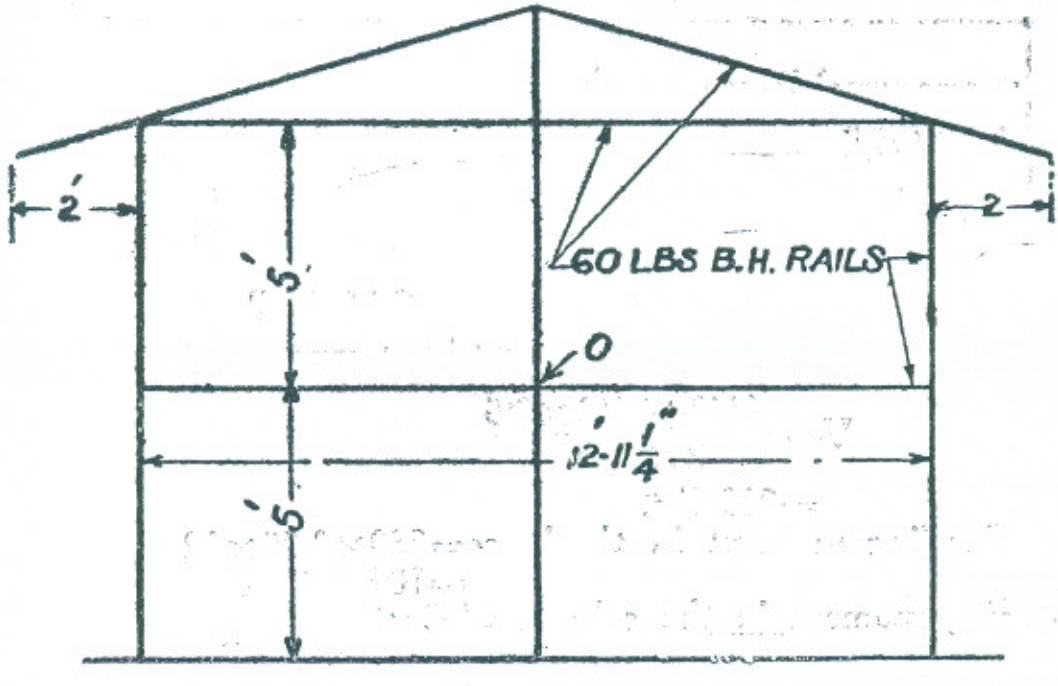
Wt. of roof	1318·7	lbs.
Wt. of rafter	178·8	,,
Wt. of braces	130·0	,,
Wt. of columns $\left(\frac{7·17}{2}+5\right)\times 20$	171·8	,,
Wt. of brickwork panel	1706·25	,,
Wt. of triangular panel	369·69	,,
Total ...	3875·24	lbs.

Assuming the acceleration due to earthquake ·075g, the horizontal force exerted on the upper storey is evidently 3875·24×·075=290·6 lbs. or say 290 lbs.

The vertical load for the lower storey on each bent is as follows :—

Wt. of upper storey	3875·24	lbs.
Wt. of brick panel	1706·25	,,
Wt. of braces	130·00	,,
Wt. of columns 7·5×20	150·00	,,
Total ..	5861·49	lbs.

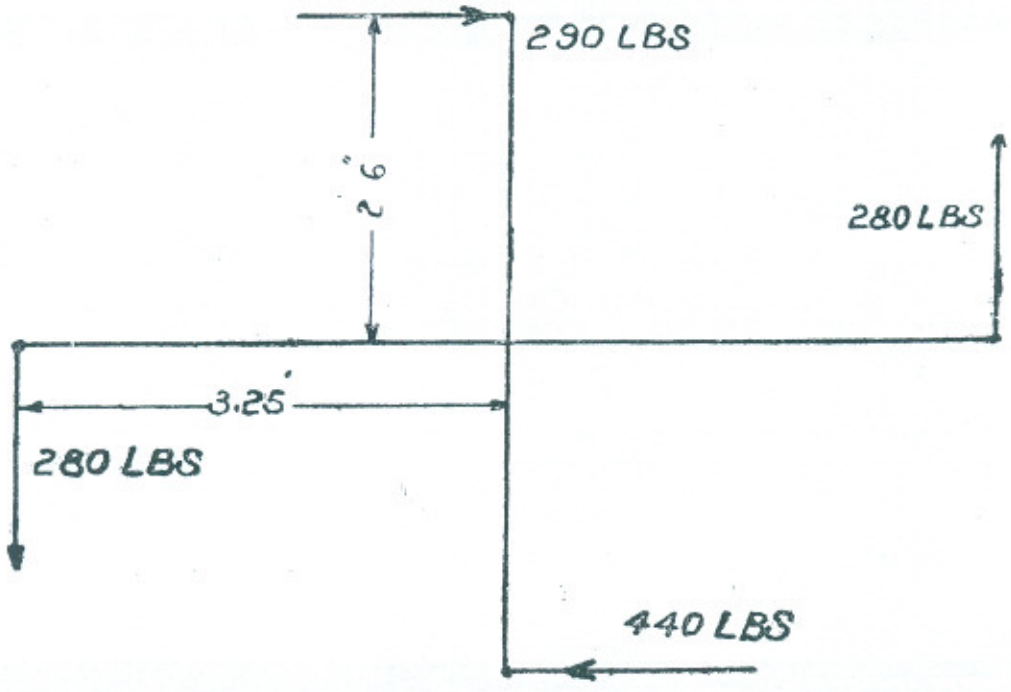
∴ Earthquake force on the lower storey
5861·49× ·075=439·6 or say 440 lbs.



The stresses due to these forces for the bents may be calculated in a manner exactly similar to that employed for wind loads. The exact method of the determination of such stresses is much complicated and tedious. The stresses in this case will be calculated by Flemings' method, which is much simpler and sufficiently accurate for bents with equal spans and equal storey heights. According to this method the total horizontal force is assumed to be divided equally between the bents and each bent treated separately for that fraction of the horizontal force. To make the solution statically determinate, the point of contraflexure in each brace is assumed at its midspan and for each column at the midpoint of each storey height. The shears and bending moments in the interior columns are of course added up algebraically, each interior column thus taking up twice the shear in the exterior columns. From this it is evident that any joint may be removed from the structure and treated as a free body, the appropriate shearing forces being applied at the assumed points of contraflexure in the columns.

(*Vide* " Steel Mill Buildings " by M. S. Ketchum, pp. 352-354 and " Concrete Engineers' Handbook " by Hool & Johnson, pp. 427-428).

Considering the joint O as a free body in this case and taking moments about it.



$$V = \frac{(440+290)\times 2{\cdot}5}{2\times 3{\cdot}25}$$

$$= 280 \text{ lbs.}$$

Bending moment in the brace $= 280\times 3{\cdot}25\times 12$
$= 10920$ in. lbs.

Bending moment in the column $= 440\times 2{\cdot}5\times 2$
$= 13200$ in. lbs.

The direct stress in the brace is very small and will be neglected.

The moment of inertia and section modulus of 60 lbs. iron rail are 1·70 in.^{4} and 1·50 in.^{3} respectively. Reducing by 12½ % for old rails, the section modulus in this case = 1·50 — ·19 = 1·31 in^3.

$$\text{Bending stress in the brace} = \frac{10920}{1{\cdot}31 \times 2240} = 3{\cdot}72 \text{ tons/sq. in.}$$

This is quite safe.

$$\text{Bending stress in the column} = \frac{13200}{1{\cdot}31 \times 2240}$$

$$= 4{\cdot}5 \text{ tons/sq. in.}$$

The direct stress in the column after reducing the area by 10% on account of old rails $= \frac{4200}{2240 \times 5{\cdot}4} = {\cdot}35$ tons/sq. in.

Total stress in the column $= 4{\cdot}5 + {\cdot}35 = 4{\cdot}85$ tons/sq. in.

The unsupported length of the column = 5 ft. and its least radius of gyration $= \sqrt{\frac{1{\cdot}49}{5{\cdot}4}} = {\cdot}53$ in. $\therefore \frac{l}{r} = \frac{60}{{\cdot}53} = 113{\cdot}2.$

The permissible stress for wrought iron in compression
= 6 tons/sq. in.

Since, however, the earthquake stresses are imposed on the structure very occasionally the safe stress may be increased by 50 per cent. the permissible stress being thus 9 tons/sq. in.

Applying Rankine's formula, the working stress in the column

$$= \frac{fc}{1 + \frac{1}{9000} \times \left(\frac{l}{2r}\right)}$$

the value $\frac{l}{2r}$ is used in this case, since the columns in the frame are rigidly connected at the joints with the braces, and have fixed ends.

Substituting the various values

$$f = \frac{9}{1 + \frac{1}{9000} \times 56{\cdot}6^2} = \frac{9}{1 + \frac{1}{9000} \times 3203{\cdot}56}$$

$$= 6{\cdot}64 \text{ tons/sq. in.}$$

The actual stress being only 4·85 tons/sq. in., the design is safe. The brick panelling also adds to the strength of the frame by taking up stresses diagonally, but this has been neglected in calculations.

APPENDIX II.

Report on the tests on cement brick panels carried out at Quetta by Mr. P. C. Neogi, S. D. O. 2, Quetta.

In connection with the construction of earthquake resisting quarters, tests were carried out to determine the strength of the panels of $4\frac{1}{2}$" thick walling.

Panels were built exactly similar to those used in the building. In one the bricks were cut so as to fit into the web of the vertical rails, in the other the space between the end of the bricks and the web of the rail was filled with mortar.

The mortar was a 1 : 4 cement and Bostan sand mixture.

The panels were allowed to set for 3 weeks before testing.

The panels were lowered into a horizontal position and the ends of the vertical rails supported on brick pillars.

The brick-work of the panel was first covered with rail pieces of the full length of the panel, but clear of the rail frame.

On these further rails were loaded until failure occurred.

Date of test 23-5-32. Place : Quetta.

Results.

1. *Bricks cut to fit web of rail.*

Size of panel 8'-3"×6'-9"	56 sq. ft.
Total load at failure	21800 lbs.
Load per sq. ft. at failure	389 lbs.

2. *Bricks uncut and joint with web filled with mortar.*

Size of panel 8'-3"×6'-9"	56 sq. ft.
Total load at failure	20060 lbs.
Load per sq. ft. at failure	358 lbs.

APPENDIX III.

Comparative cost of earthquake resisting and ordinary method of construction.
At Quetta Division Rates.

Type No.	Staff to whom allotted.	Accommodation in s.ft.		Plinth Area in s.ft.		Total Cost of building.		Rates per s.ft. on Plinth Area of E. Q. type.		Rate per s.ft. on Plinth Area of ordinary type.		%age increase in rate.	
		Main Room	Other than main room.	1st Unit.	Addl. Unit.	1st Unit.	Addl. Unit.	1st Unit.	Addl. Unit.	1st Unit.	Addl. Unit.	1st Unit.	Addl. Unit.
						Rs.	Rs.	Rs.	Rs.	Rs.	Rs.		
Q. 26 E.	Menials ..	..	145	216	184	1,116	848	5·17	4·61	3·70	3·02	40	53
Q. 27 E.	Junior Subordinates ..	240	184	587	539	2,915	2,598	4·97	4·82	3·82	3·51	30	37
Q. 28 E.	„ „ ..	341	527	1,157	1,122	5,499	4,993	4·75	4·45	3·47	3·29	37	36
Q. 29 E.	Senior „ ..	619	903	1,879	1,842	7,451	6,840	3·97	3·71	3·51	3·40	13	9
Q. 30 E.	„ „ ..	625	803	1,782	..	7,056	..	3·96	..	3·46	..	14	..
Q. 32 E.	„ „ ..	949	1346	2,798	..	10,551	..	3·77	..	3·32	..	14	
Q. 39 E.	Asstt. District Officers	1,276	1960	4,033	..	13,365	..	3 ·1	..	3·07	..	8	...

Note.—For the sketch plans of these types of quarters, see Plate VI.

DISCUSSION.

Mr. Kumar introducing his paper remarked that when he was called upon, in September 1931, to design earthquake resisting quarters for the Railway staff in Baluchistan, he experienced considerable difficulty in obtaining any useful information on the theory of earthquake resisting construction.

There was not a single book in the N.-W. Railway Headquarters Office Library at that time or in any other Library at Lahore, which could give more than half a page or at the most a page on the subject. This lack of literature was due to two reasons. In the first place, the United Kingdom was free from severe earthquakes, and secondly the science of applied seismology was still in its infancy. All the literature in the English language on this subject had recently been produced in America where on account of the frequency of violent earthquakes and on account of the zeal and interest shown by certain pioneers, like Mr. Freeman, considerable attention was now being given to the subject.

The speaker remarked that Col. Macrae, the Chief Engineer of the N.-W. Railway, had realised his difficulties and those of any other Engineer who set himself to the task of designing earthquake resisting buildings. He therefore asked the speaker when he had completed the design of earthquake resisting quarters in Baluchistan, to compile all the information that would be useful to a Structural Engineer on the subject. The author took this opportunity to express his sincere thanks to his Chief Engineer for the kind and valuable help he gave the author in getting out this paper and for permitting him to present it to the Congress.

The speaker stated that he had explained in his paper that Assam, Arakan and Bengal and areas round Kangra and Mussorie had been subject to violent earthquakes in the past, and that Baluchistan and the Indo-Gangetic plains had frequently been shaken by earthquakes of considerable intensity. The Assam earthquake of June 1897 was the severest ever recorded in the seismic history of the world. Considerable damage was also done by the Kangra earthquake of April 1905, but like all other catastrophies in India it was treated as a visitation of God's wrath and as forgetfulness is a trait of human nature nothing more was done. Thus there was at present not a single seismograph of any kind within 200 miles of Kangra or Mach in Baluchistan. During his tour in Kangra District last year the author had noticed that most of the buildings were of such inferior construction that the next shock would cause as much loss of life and property as the last one. Mach bazar rebuilt after the earthquake of August 1931 was still as much susceptible to a average earthquake as the one it replaced. Clearly therefore, it was the duty of every Engineer that the havoc wrought by these earthquakes was not forgotten and that every building in his charge

was suitably designed and built with earthquake stresses in view. The author was glad to say that the N.-W. Railway administration had taken the lead in this matter by building earthquake resisting quarters on such a large scale and at such a time when the money was very scarce.

The responsibility of Engineers in this matter, the author thought, was greatly increased on account of the impossibility of earthquake prediction. No destructive earthquake had ever yet been predicted. Although some corelation had been found to exist between the tilting of the ground and certain meteorological phenomena, such as barometric pressure, rainfall, tides and cyclones on the one hand and the occurrence of the earthquakes on the other, yet it appeared that these phenomena had merely acted as triggers in releasing the tremendous strains which the earth crust had been subjected due to subterranean causes. Thus it would appear that these phenomena did not provide sufficient and essential data for earthquake prediction. Until it was possible for the seismologist to predict a coming earthquake with respect to its time, place and severity, the safety of human life and property lay entirely in the hands of the Engineers in countries subject to severe earthquakes. This paper would not have been written in vain if it were able to cast off the present complete indifference of Engineers, architects and others engaged in building trades to the earthquakes problems. The duty of the Government, the corporations and the municipal bodies was also clear. There should be legislation to penalise any building construction which was not certified to be safe by a competent engineer, more especially in the case of those buildings to which public resorts for recreations, such as cinemas, theatres, dancing halls, etc.

Unfortunately this year due to certain circumstances, the speaker continued, the papers were received very late and most of the members had got this paper only on the previous morning. Thus they had no time to go through it or to raise any points for discussion. The speaker stated that he would be glad to supply further information on the subject to any body and to discuss any point raised in this paper.

Mr. P. Everall discussing Mr. Kumar's paper said that he had read with considerable interest Mr. Kumar's paper on "Earthquake Resisting Buildings and Structures in Baluchistan." He was interested in the subject because the Bridge Branch which was under his charge, had considerable work to do on repairs to certain bridges damaged during the earthquakes of August 1931. He had an opportunity of visiting the scene of the disturbance just after the major shocks had taken place, and of seeing the damage which had been done to many of the buildings in the centre of the earthquake zone. He was chiefly interested in a large double track bridge about 1 mile north of Mach consisting of 2 spans of 150 ft. one of 100 and one of 60 ft. under each ballasted track. This was the most seriously damaged bridge on the section and required considerable attention before it was rendered fit again for normal traffic.

During the earthquake, so violently were the girders thrown backwards and forwards both transversely and longitudinally that two piers 50 ft. in height were badly cracked in the horizontal plane midway between the pier caps and base. The piers had moved bodily inwards a distance of 6", and most if not all the bearings were damaged. The rollers at the expansion ends being badly displaced and the cast iron location lugs at the fixed ends being broken off and rendered ineffective. Owing to the closing in the *nallah* and consequent displacement of the piers, the end raker members of the larger spans were also badly damaged. In order to carry out repairs effectively staging units of the standard type which they kept available for bridge works, were built up from the river bed to support the spans while the damaged girder members and bearings were replaced, traffic being maintained throughout the work.

The foundations of the bridge appeared to be founded on conglomerate overlying strata of sedimentary rock. The station of Mach on the other hand was situated on alluvial soil and detritus and in consequence suffered much more severely. The particulars of the geological features of the part of Baluchistan are dealt with very fully in a note on the Baluchistan earthquake of August 27th, 1931, recently prepared by Mr. W. D. West, M.A., of the Geological Survey of India.

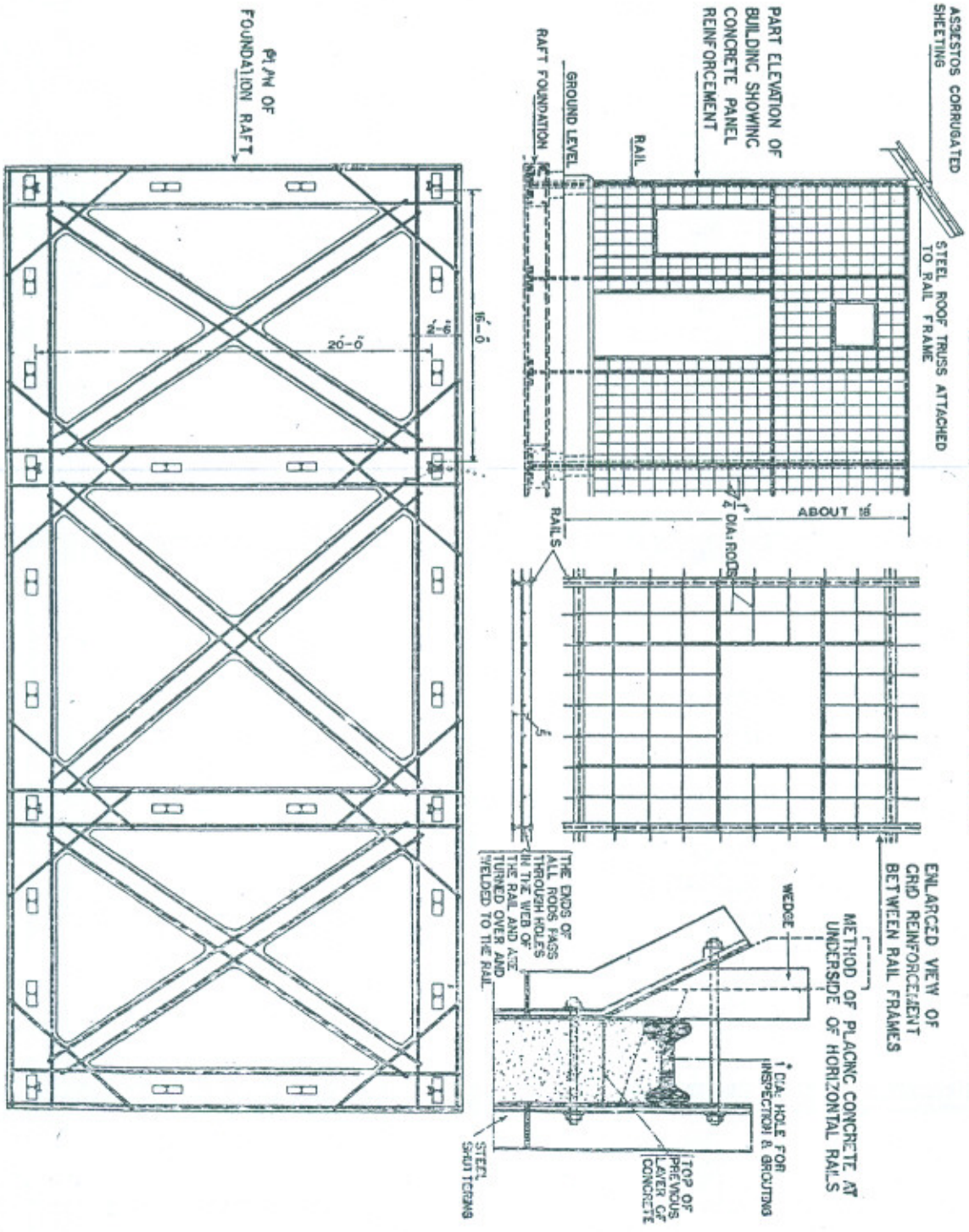
One other bridge worthy of note which was damaged although not so severely was situated near Sharigh. In that case the steel work escaped but a large portion of masonry from the top of one of the piers sheared through at an angle of about 45°. Bridge staging was again requisitioned and erected in order to relieve the damaged pier of its load and enable rebuilding to proceed without delay to traffic.

Buildings. Regarding the design of buildings to withstand earthquake shocks especially when founded on alluvial soil, it is generally accepted that the structure should be as monolithic as possible and should be capable of movement as a whole during the shock. Its foundations should preferably be of some form of raft construction ensuring the base of the building being rigid.

The form of construction described in Mr. Kumar's paper is suitable for quarters which are limited in size and height but he considered that it is not so suitable for larger structures such as four roomed bungalows and main station buildings.

or these buildings the foundation requires to be sufficiently rigid to resist both horizontal and vertical vibrations. The rail framework should be provided with robust end connections and preferably some form of efficient bracing. In the type of structures built there is considerable danger of the brick panels between the rail frames becoming displaced and falling down on to inmates of the buildings. He suggested that for important buildings, foundations similar to those illustrated by the

diagram on page 181 would be more suitable. These foundations consist of reinforced concrete beams braced diagonally with other concrete beams and forming what may be termed an open raft.



For the skeleton framework of the building, rails or light steel sections such as R. S. joists are used, but instead of brickwork forming the panels, reinforced concrete is provided, details were shown on the diagram. The reinforcement, which formed a grid between the rail frames consisted of rods $\frac{1}{4}$" to $\frac{5}{16}$" dia. spaced about 9" apart, the ends

pass through small holes drilled in the web of the rails to which they are secured by means of a simple welded connection. The concrete panel is 5" thick, it could be conveniently formed in position by means of interchangeable steel shuttering and the different component parts of the building would be standardized and made as few in number as possible.

One feature of interest is the method of ensuring that the concrete was filled right up to the underside of the horizontal rail—a detail of which is shown on the diagram on page 181.

The suggestion to use concrete is made principally because of the accessibility of excellent small shingle and coarse sand in the river *nullahs* close to Mach and in other parts of Baluchistan. The writer is confident that a building built on those lines would be capable of resisting severe earthquake shocks. The superstructure is to some extent flexible but the building, being seated on a raft foundation would act as a whole during a shock and not tend to split up and vibrate in different planes. The particular form of construction simplifies the fitting up of doors and windows in the building since they could be introduced into the panel reinforcement.

The roof covering would be as light as possible on steel trusses securely attached to the vertical frames. For the covering asbestos sheets are suggested.

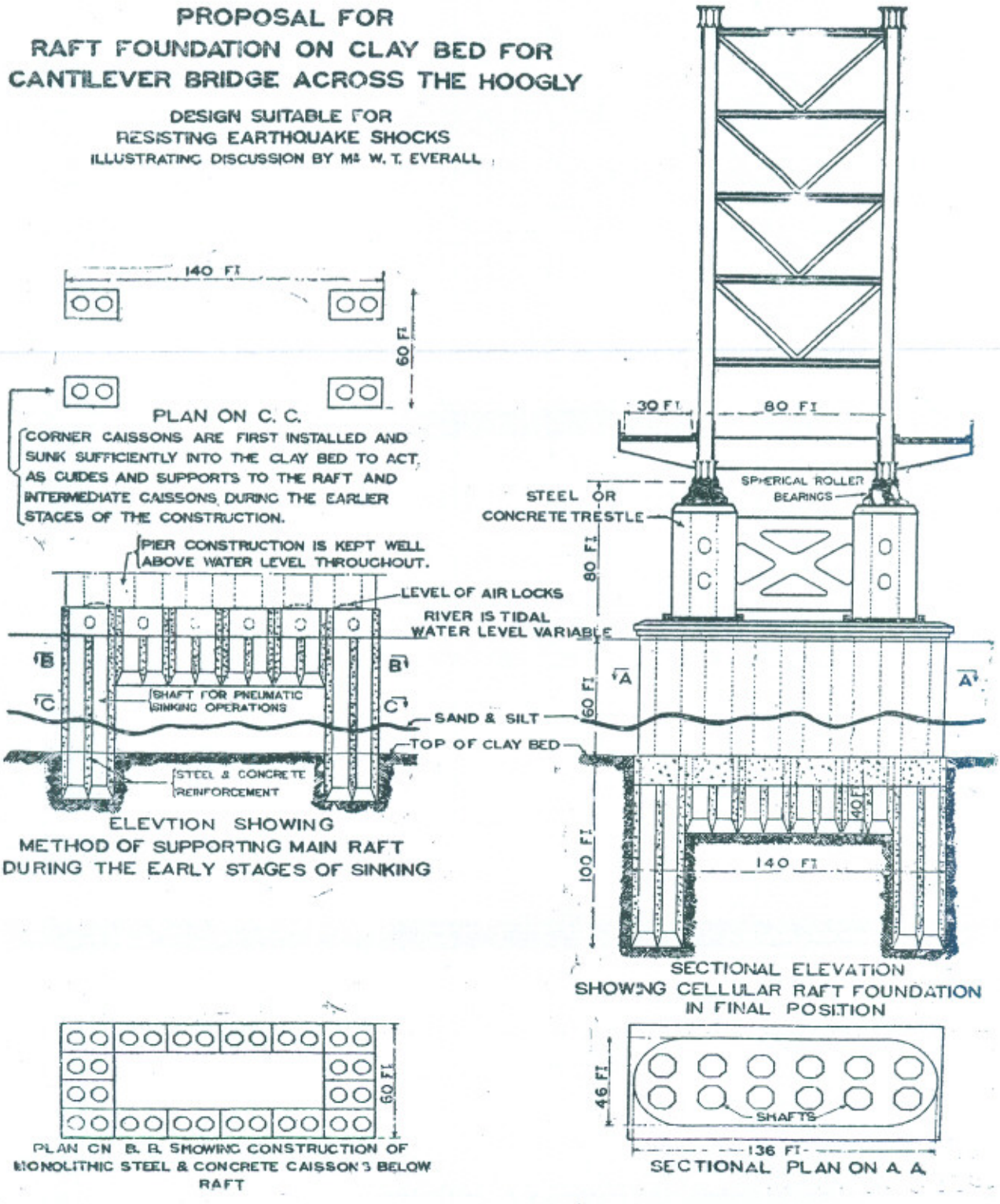
An alternative to the proposal would be to make the buildings of precast reinforced concrete units, which would be erected and bolted together on rigid foundations, but the question of high cost would probably rule that out as a practicable proposition for a country like Baluchistan.

Although not directly connected with the disturbances in Baluchistan but as it concerned the subject of earthquakes, Mr. Everall mentioned that last year he received a letter from a Consulting Engineer in London, asking him if he could obtain particulars of the effects of the Assam earthquake which occurred in June 1897; this was one of the worst earthquakes on record in India and it caused considerable damage throughout the whole of Bengal and Assam including Calcutta. In particular, information was asked for concerning the effects of this earthquake in places where heavy alluvial deposits occurred, either on the top of rock or on clay beds, such as was found in the vicinity of Calcutta, where sand and silt and alluvial deposits extend for about 60 feet above the main clay bed.

He took advantage of being in Calcutta last December to make some enquiries. He obtained much interesting data from Mr. West of the Geological Department, who was particularly interested in earthquake disturbances in India. It appeared that in regions where heavy alluvial deposits rest upon rock or heavy clay beds that the effects of an earthquake were intensified and in provinces like Bengal where those conditions obtained, they were likely to be very severe. Apparently those

conditions had been recognised, because in the case of the Victoria Memorial Buildings built in Calcutta at the cost of nearly a crore of rupees, the foundation is definitely of a raft type and designed purposely to resist earthquake shocks.

Mr. Everall considers that in view of the possibility of earthquake shocks occurring in Bengal it would be very undesirable to build a sus-



pension bridge at Howrah across the Hooghly River or anywhere in the neighbourhood of Calcutta. On the other hand a bridge of the cantilever type, on raft foundations would be most suitable. In dealing with foundations, however, which have to be designed to suit such special conditions, some departure from ordinary practice might be necessary and he has in this connection put forward a suggestion for foundations for a large cantilever bridge capable of carrying a weight of 40,000 tons and among other things, to provide for the necessary stability to resist earthquake shocks. The proposed pier construction and foundation are illustrated by the diagram on the previous page.

The foundation is of cellular construction and consisted of steel and reinforced concrete caissons sunk pneumatically for a depth of about 35'-0" into the clay bed ; it forms a raft 140 ft. long by 60ft. wide with cellular side extensions for confining the clay beneath the central portion of the structure, the total nett pressure exerted in the clay bed would be about 5 tons per square foot.

The caissons at each of the corners would act as guides and support to the main structure in the earlier stages of the sinking and to those corner caissons, the raft and intermediate caissons, after floating out, are attached.

The four-corner caissons would possibly have to be sunk to a depth of 100 feet into the clay bed.

Col. Macrae in discussing Mr. Kumar's paper remarked that the author had done a great deal of good work in collecting information on which to base design for earthquake resisting buildings.

The author's note on the Baluchistan buildings in its description of the earthquakes there, appeared to him to paint an incomplete picture that gave a wrong general impression of these earthquakes. It had not been a case of a Mach earthquake but of series of shocks with different centres in Baluchistan, spaced over a long period, and in some places the shocks had been followed by a continuous succession of tremors, producing on people the effect of waves.

The first main shock was centred near Sharigh on the Harnai route over 30 miles from Mach with large intervening hills, and took place a 3 A. M. on Tuesday, the 25th August, 1931, $2\frac{3}{4}$ days before the first main shock at Mach on the Bolan route. Some of the intermediate shocks between these two, and also some later ones, were felt at Quetta practically as severely.

At Mach during the night that followed the main 9 P.M. shock of Thursday, the 27th August, many people were sick from the continuous wave motion of the ground, so much so that the Station Superintendent marked out areas for them to retire to.

The Dozan springs that for 40 years had supplied water to the Railway for the section Hirok to Kolpur above Mach was reduced to half supply by the main Mach shock, and vanished altogether after another

shock about a month later, and it was from such later shocks that some of the buildings on the Putt section below Sibi collapsed.

Shocks producing slight damage had always been comparatively frequent in Baluchistan.

Accompanied by other Railway Engineers, the speaker had been the first person from outside Baluchistan to get up to Mach after its main shock, getting there by trolly from Mushkaf on Sunday, the 30th August trollying included a lot of time carrying the trolly over obstacles ; in fact few from outside Mach had got there, the small number including the Divisional Superintendent and the Divisional Executive Engineer of the Quetta Division, North Western Railway.

Panir, 21 miles by Railway below Mach, was as badly flattened out as Mach itself ; the Sub-Divisional Officer and the Permanent Way Inspector from Mach had managed to get down to Sibi to meet him and the Divisional Executive Engineer coming from Sharigh *via* the Kachha Kotal and Quetta met him near Panir. A Sub-Assistant Surgeon came from Sibi with him on a second trolly to Panir bringing bandages, etc., to attend to those damaged, some of whom had broken limbs.

It could be realized that he had seen the damaged structures before any clearance had been done except the minimum for digging out people, and that he had received many personal descriptions of the earthquake shocks.

His impression had been that the line of shocks were all practically identical at Mach, but that some of them had probably reversed their direction in the manner that water waves reverse direction after hitting a beach.

The nature of the earthquake had been, he understood, the same as those in Dharamsala region, due to settlement into hollows originally caused by later formation pushing up past older and more stable formations and probably the shock waves caused one large settlement and induced further settlement elsewhere and further shocks.

At Mach one could note a similar condition of walls to that of the remains of bungalows at Dharamsala, those in one direction being sheared off closer to the ground than those in directions more or less at right angles, a fact he had noted when Dharamsala came into his M.E.S. charge before he had got back to Railways from military service during and after the war.

Col. Macrae further remarked that Mr. Kumar had clearly brought out the fact that alluvial soil near the rocks was in general particularly susceptible to this kind of earthquake shock, producing severe effects on buildings ; and the site of the Railway colony at Mach on a high old alluvial bank of soil and gravel, surrounded by rocks except on the river side, had illustrated this fact in a lamentable manner.

Regarding Mr. Everall's remarks in connection with the use of reinforced concrete for earthquake resisting construction the speaker stated that the Projects and Design Branch had put up to him the estimates

of staff quarters using reinforced concrete. As the cost of these quarters was very high and as it was not possible to make adequate arrangements for supervision, the idea of using reinforced concrete was abandoned.

It was a practice a few years ago, the speaker remarked, to indicate on the plans of buildings the direction of the Kangra earthquake. This information had been found useful in designing a church at Lahore. He did not know why this practice had been given up.

Mr. S.L. Malhotra in discussing Mr. Kumar's paper said that the gratitude of the whole of the profession in the province was due to Mr. Kumar for his pioneer work on the subject which he hoped would prove very useful to the earthquake-effected areas in general and the consulting engineers and architects in particular. Not being conversant at the time with the theoretical aspect of the subject and theory of harmonic motions, he would confine his remarks to the descriptive portion of the paper.

It appeared that the walls of a building considered as fixed in the ground would act in an earthquake as oscillating cantilevers and develop tensile stresses on both faces alternately. If this were so, reinforced concrete would in his opinion be a more suitable material for earthquake-proof building than steel frames advocated by Mr. Kumar on pages 156 and 157 of the paper. Tensile stresses being predominent, full advantage of steel would be derived in reinforced concrete structures and that was why steel works were being fastly replaced by reinforced concrete everywhere. The compressive stresses would not in his opinion exceed the safe limits for concrete.

He agreed with the author that the vertical motions in an earthquake would not cause much damage to a building unless it happened to be situated on a fault plane and was subjected to a great upheaval.

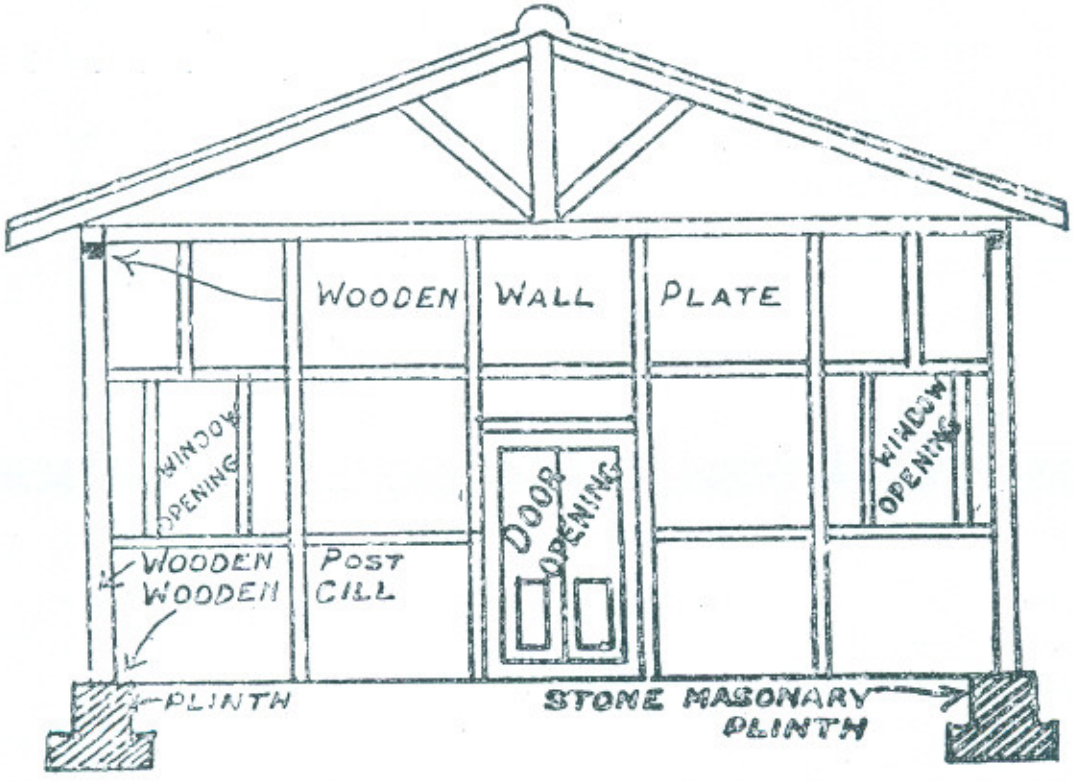
Further while proposing thin masonry walls in steel frame buildings in Baluchistan Mr. Kumar seemed to have forgotten another factor which should have been kept in view. Besides the defects pointed out by Mr. Everall a 9" brick outer wall could not be expected to offer any resistance to thieves and burglars and was thus quite unsuitable. Having got the unfortunate experience of the great difficulties involved in dismantling a damaged R. C. glacis of a fall, he was of opinion that even a 6-inch thick R. C. wall was almost impossible to be pushed through. Evidently, therefore, an ideal earthquake-proof building would consist of rigidly fixed and deep foundations with thin concrete walls, reinforced on both faces. The mat and slab type of R. C. foundations advocated by Mr. Kumar would serve the purpose well.

Regarding division of India into zones of varying earthquake intensities he could not think of any hard and fast line that could be drawn by Mr. Kumar. A violent earthquake in Kangra for example would not go without some damaging effects at Lahore as happened in 1905. In his opinion Lahore ought to have been included in the zone of strong earthquakes.

Regarding specification for earthquake-proof buildings, he hoped that the author would try to explore the possibility of using reinforced brickwork for walls in place of ordinary cement masonry, thus obtaining greater tensile strength. Although the cost of such work would be higher, but it would ensure greater safety against earthquake forces.

R.B. Mangal Sen Dhody, narrating the account of the earthquake in Assam in 1897 stated that his first appointment was in Shillong in July 1899. At that time the entire Civil Station, the Government House and other big buildings had come down. They rebuilt most of them from 1898—1902. He remarked that he would briefly let the Congress know by a few sketches what procedure was then adopted for reconstructing the buildings. At that time reinforced concrete construction had not come into use. Each building was first given a masonry plinth from one foot to two feet high. On the plinth was erected a wooden frame-work to give cills, posts and wall plates, which were stiffened by using flat iron elbow bends at important joints. The wall space was suitably divided by intermediate posts and horizontals into panels which were filled with lath and plaster walling by using local reeds. Roof trusses were laid on the wall plates as per sketch.

SECTION ACROSS A ROOM



Mr. Dhody then demonstrated by means of diagrams (not reproduced) on a blackboard the kind of damage done by the earthquake to waterfalls and other structures. The houses that escaped any serious damage were small thatched houses of the original inhabitants of the place. These had reed walls plastered over and simple trussed roofs. From these was developed the idea of building earthquake-proof houses as above indicated. This idea was later on endorsed by Professor Omori of Japan where earthquakes had caused havoc on many occasions and where they had carried out many experiments in a laboratory specially fitted with oscillating tables, on the stability of walls and structures.

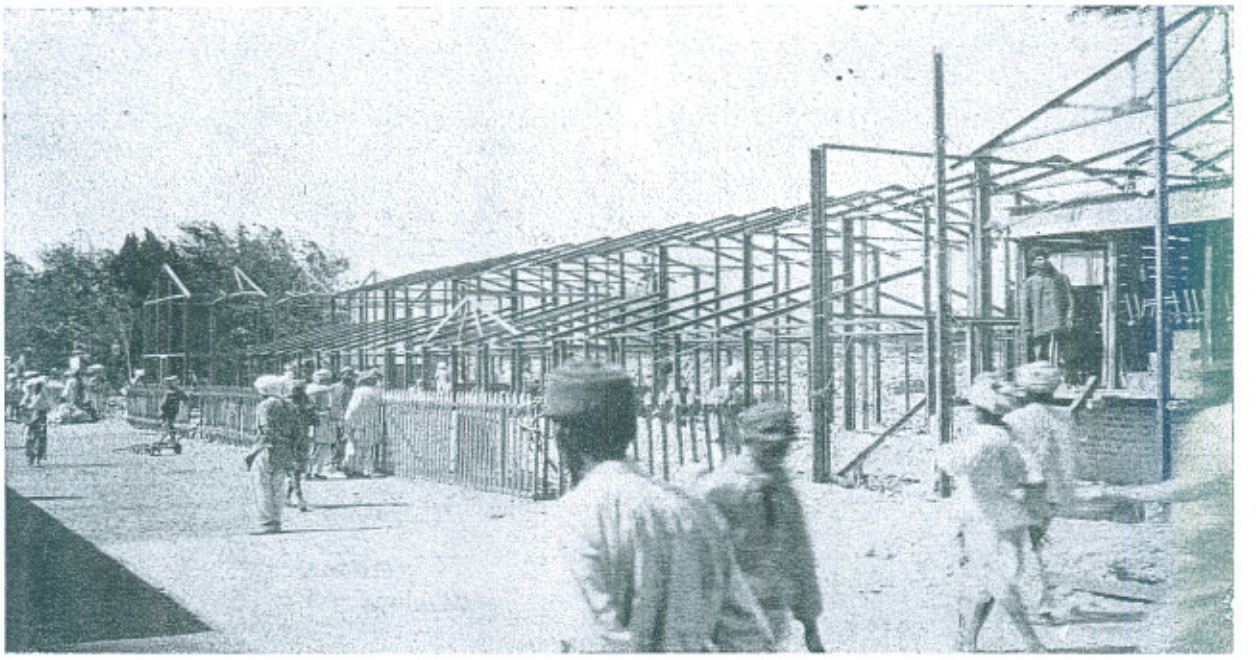
Mr. Dhody stated that although there had not been very severe earthquakes since but those that did come and there were many of them, caused no damage to the buildings that were rebuilt after the earthquake of 1897.

Mr. Astbury after congratulating the author on the useful paper he had written remarked that he had been studying the subject since 1905. He knew that the literature on the subject was very rare. The paper gave a great deal of information on the subject in a very concise form. The speaker thought that the paper would, perhaps, be more useful if a fourth appendix could be added, giving reference to the various books and papers which had been consulted by the author. There were certain foot-notes but they were not quite complete. On page 162 reference was made to article 31 of the Italian regulations issued in April, 1930. When the speaker was studying this subject, he had the Italian regulations before him—but they were all in Italian. He enquired of the speaker if English translation of these articles were now procurable or were they still in Italian.

The Author in replying to the discussion remarked that both Mr. Everall and Mr. Malhotra had laid great emphasis on the use of reinforced concrete for the foundations and the walls of earthquake resisting buildings. Although this point had been replied to by him in para. 1 on page 170 of the paper and also by Col. Macrae in his remarks yet he would drew their attention to Appendix III, page 177. It had been shown that the cost of construction adopted for the earthquake resisting quarters in Baluchistan exceeded the cost of ordinary construction by 8 p.c. to 40 p.c. As the number of quarters built for the superior staff was much less than that for the inferior staff the average excess in cost could be roughly estimated at about 25 p.c. If reinforced concrete construction had been adopted the cost would have exceeded by more than 100 p.c. Such expensive construction was not justified at the present period of grave financial stringency.

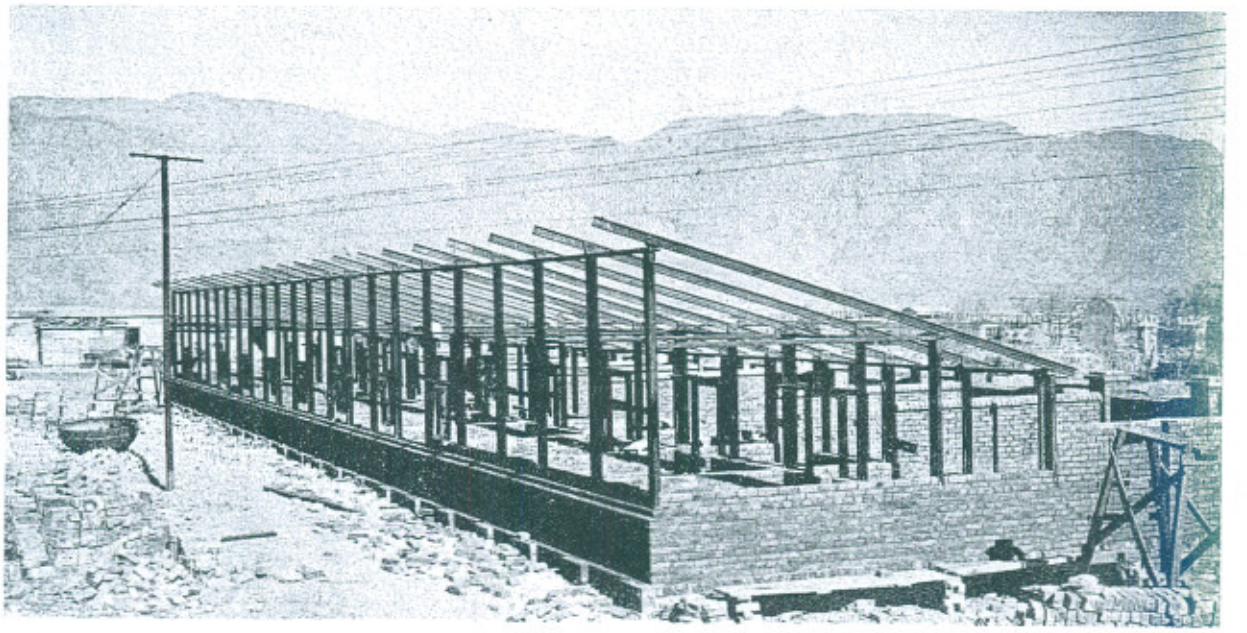
Although the indication of the direction of Kangra earthquake on plans of buildings, recommended by Col. Macrae, would certainly serve a very useful purpose of reminding the Engineer of the danger of earthquake and would thus, probably result in the removal of such structural features as would be vulnerable in a severe earthquake yet apart from this indirect gain it had no advantage. The author had

PHOTO NO. 2



STEEL-FRAMEWORK FOR MACH STATION BUILDING.
[PHOTO BY MR. MARTYN].

PHOTO NO. 1



AN EARTHQUAKE-RESISTING QUARTER UNDER CONSTRUCTION.
[PHOTO BY MR. MARTYN].

PLATE 1

MAP OF WESTERN INDIA

Showing

ISOSEISMALS OF MACH EARTHQUAKE

of Aug. 27, 1931

[Rossi-Forel Scale]

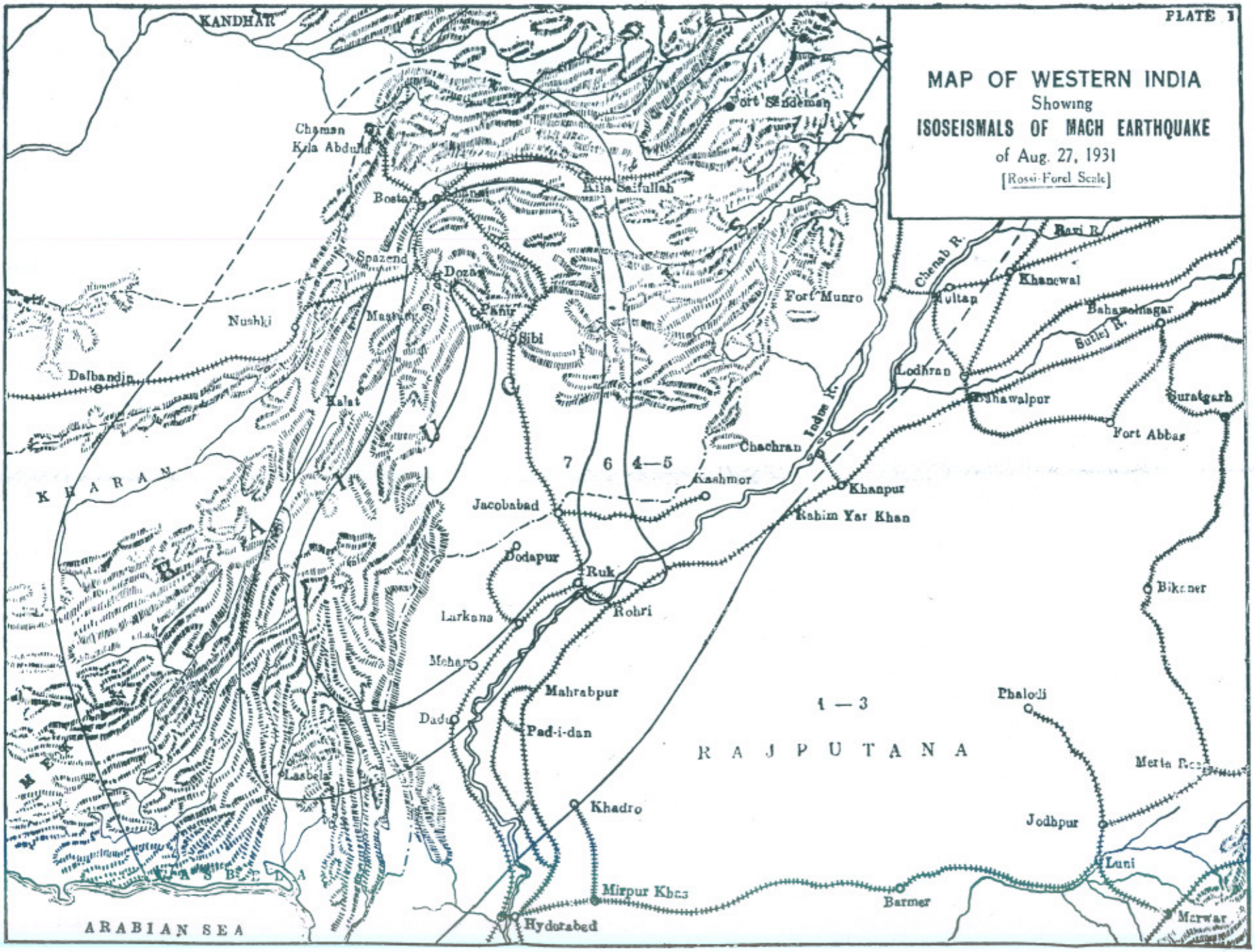
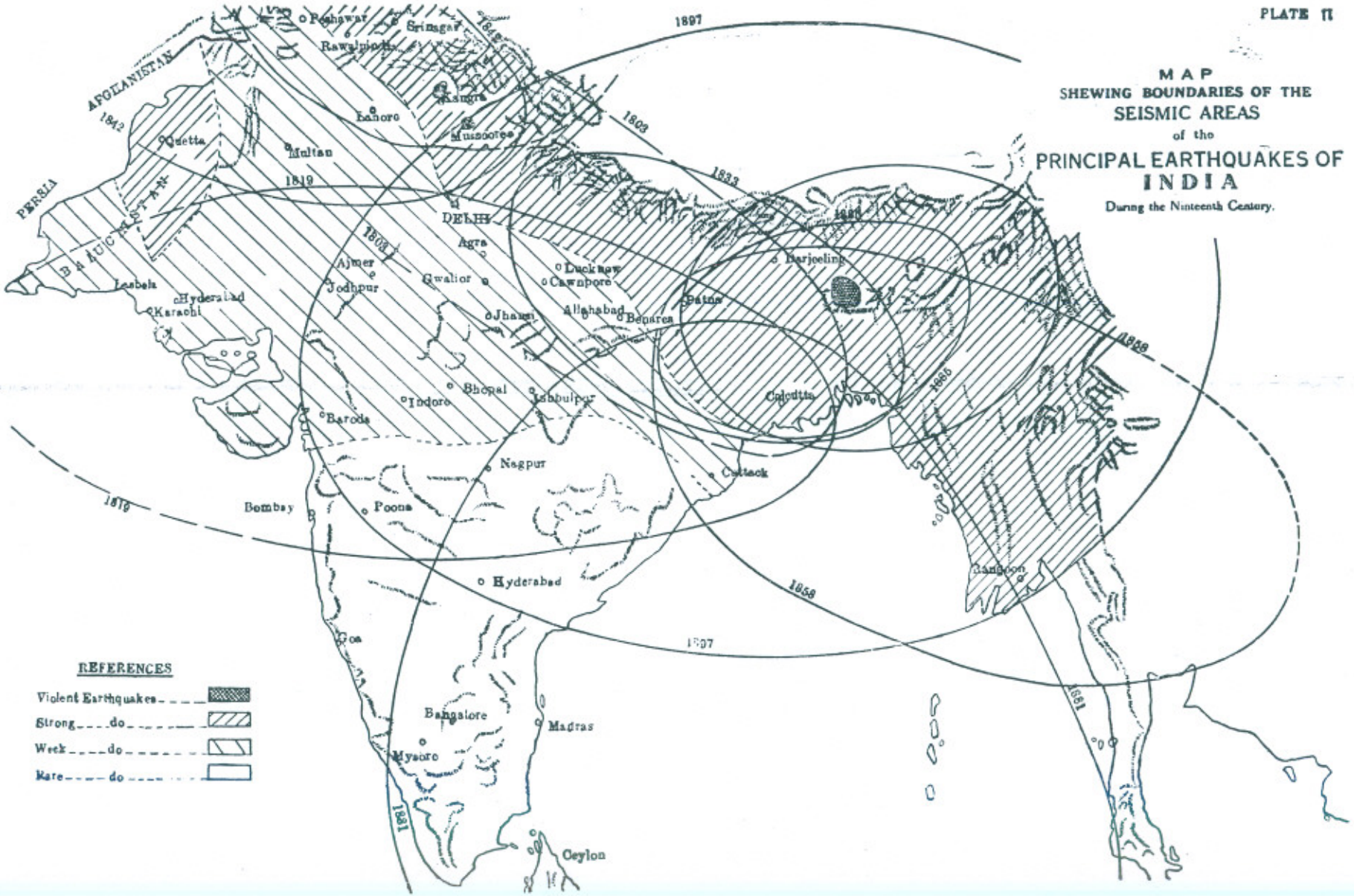
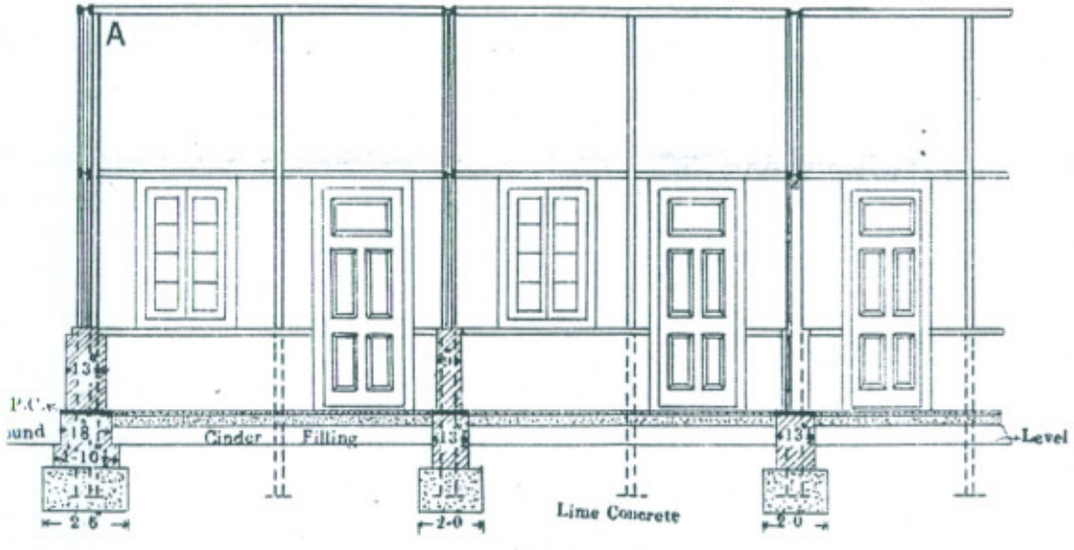


PLATE II

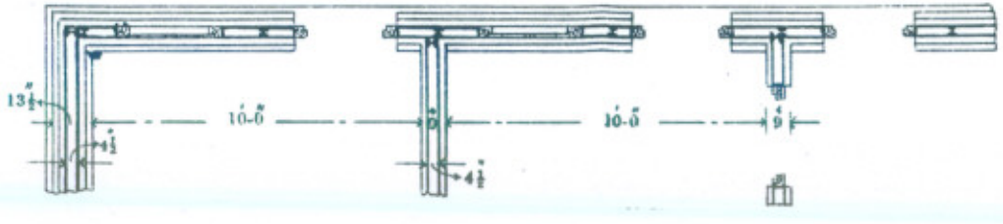
MAP
SHEWING BOUNDARIES OF THE SEISMIC AREAS of the PRINCIPAL EARTHQUAKES OF INDIA
During the Nineteenth Century.



SECTIONAL ELEVATION

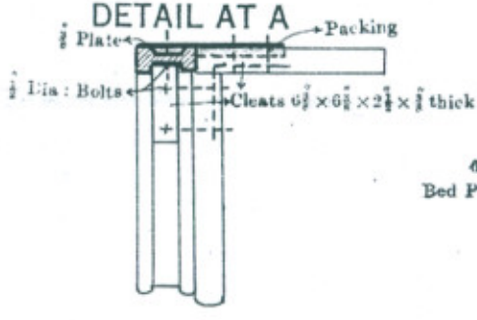


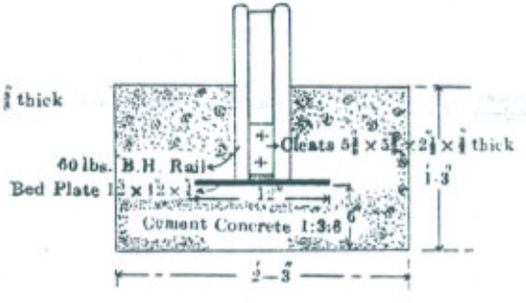
KEY PLAN



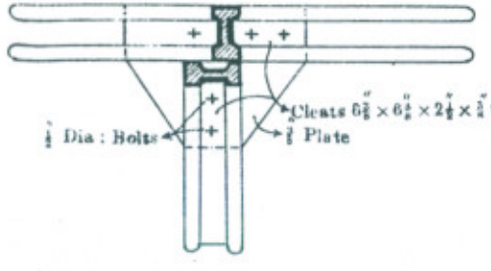
FOUNDATION OF SINGLE RAIL COLUM

DETAIL AT A

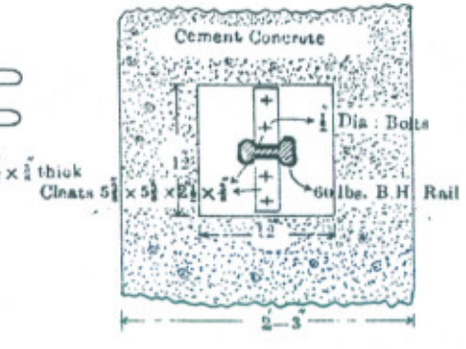




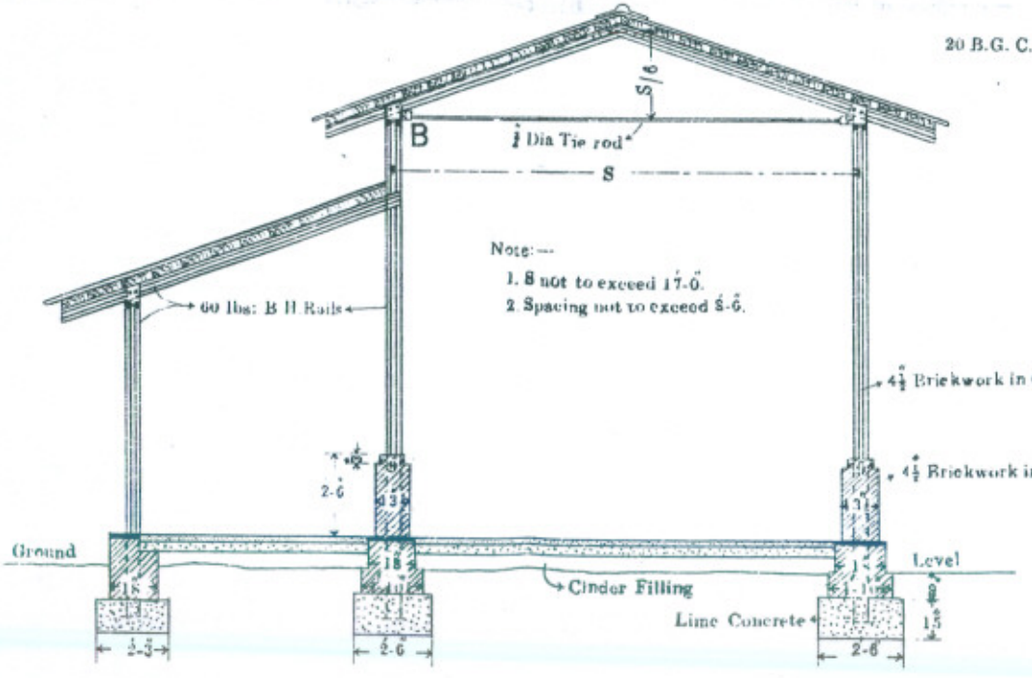
PLAN LOOKING UP



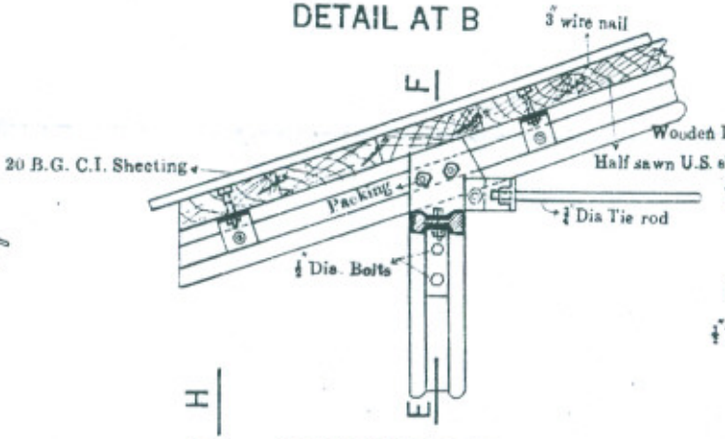
PLAN



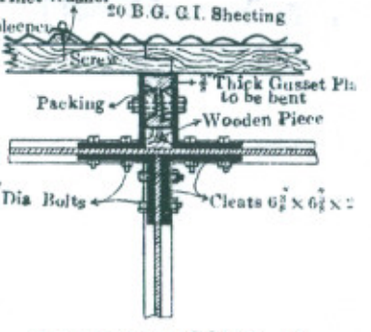
ROOF TRUSS



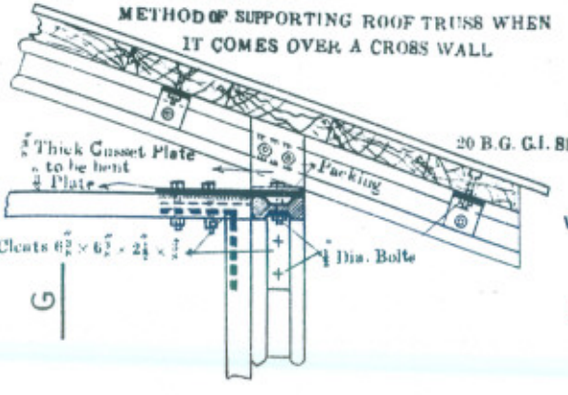
DETAIL AT B



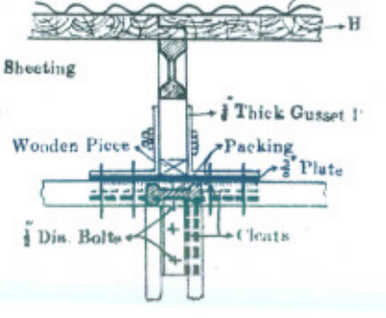
SECTION ON E. F.



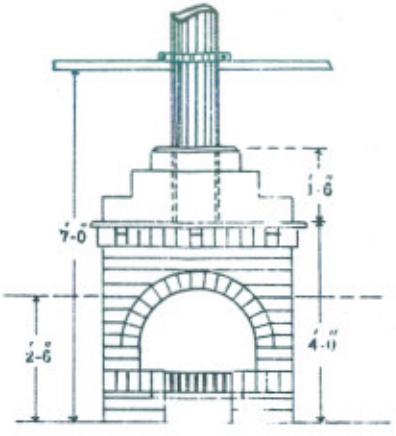
METHOD OF SUPPORTING ROOF TRUSS WHEN IT COMES OVER A CROSS WALL



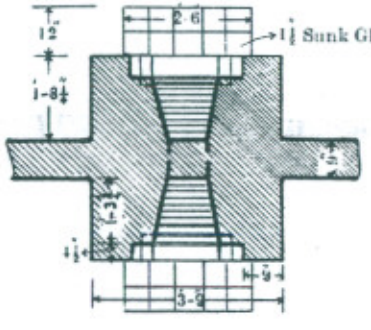
SECTION ON G. H.



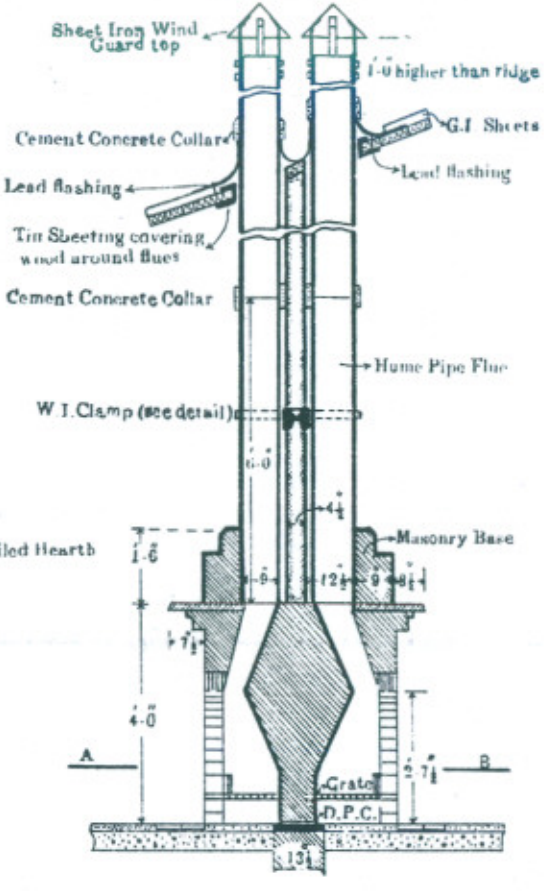
ELEVATION



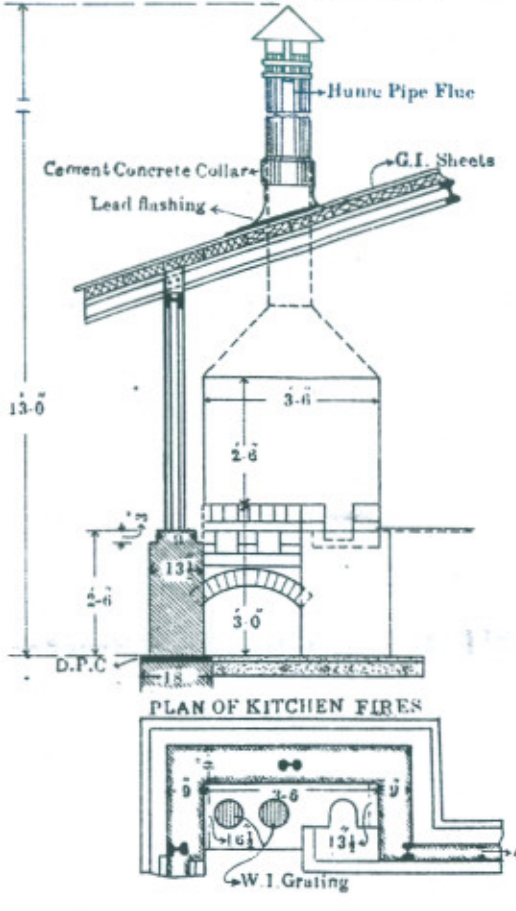
PLAN AT A. B.



CROSS SECTION



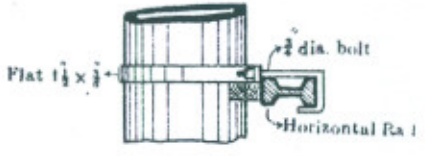
SECTIONAL ELEVATION



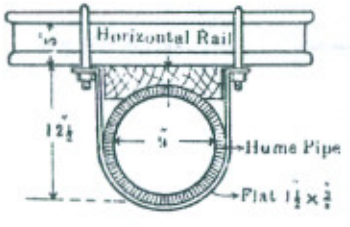
PLAN OF KITCHEN FIRES

DETAILS OF W.I. CLAMP

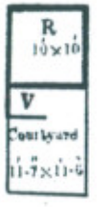
SIDE ELEVATION



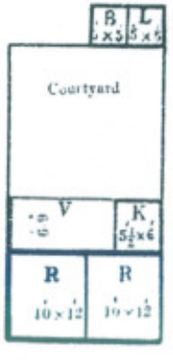
PLAN



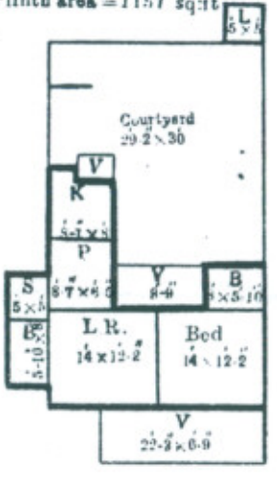
Q.—26 E
Plinth area = 216 sq:ft



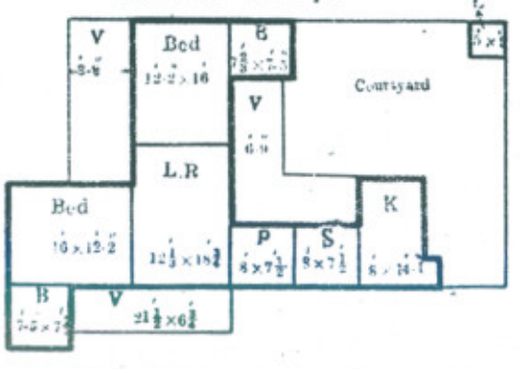
Q.—27 E
Plinth area = 587 sq:ft



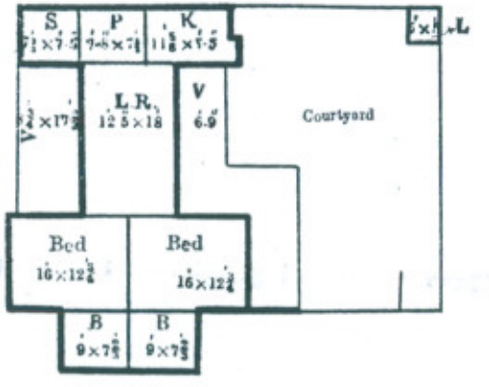
Q.—28 E
Plinth area = 1157 sq:ft



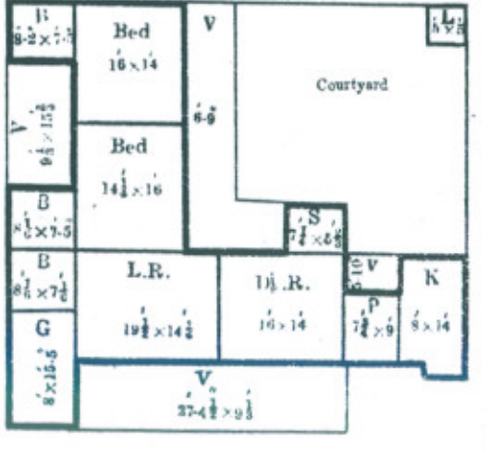
Q.—29 E
Plinth area = 1879 sq:ft

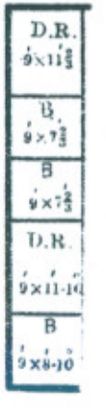


Q — 30 E
Plinth area = 1782 sq:ft



Q.—32 E
Plinth area = 2798 sq:ft





REFERENCES

- B = Bath Room
- C.H. = Chabutra
- C.Y. = Courtyard
- D.R. = Dressing Room
- D.R. = Dining Room
- F = Fuel
- G = Godown
- G. V = Glazed Verand
- K = Kitchen
- L = Latrine
- L. R. = Living Room
- P = Pantry
- S = Store
- V = Verandah

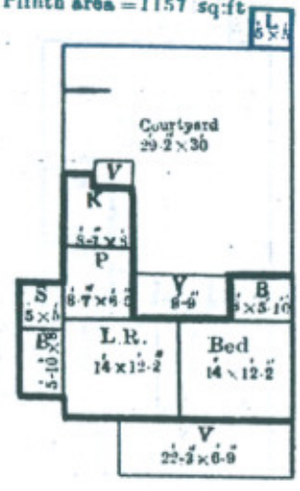
PLATE VI

N. W. R.
SKETCH PLANS
of
EARTHQUAKE RESISTING QUARTERS

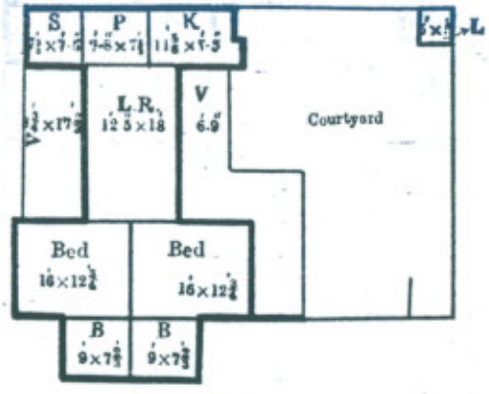
REFERENCES

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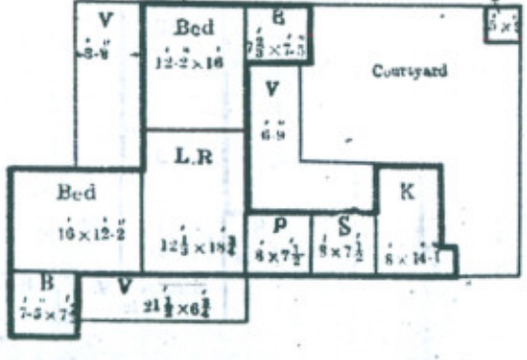
Q.—28 E
Plinth area = 1157 sq:ft



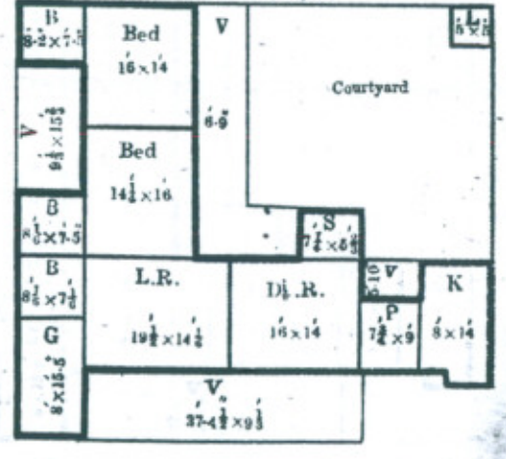
Q—30 E
Plinth area = 1782 sq:ft



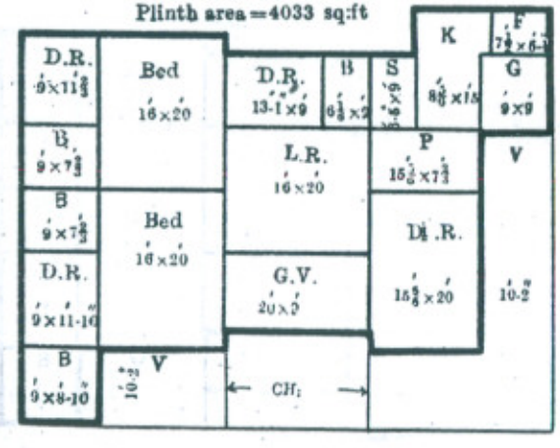
Q.—29 E
Plinth area = 1879 sq:ft



Q.—32 E
Plinth area = 2798 sq:ft



Q.— 39 E
Plinth area = 4033 sq:ft



explained in para. 2 on page 163 that there was no fixed direction from which an earthquake could be expected.

The author informed Mr. Astbury that the English translation of the Italian regulations for earthquake resisting construction was available in the excellent book *Earthquake Damage and Earthquake Insurance* by Mr. Freeman.

The form of construction used in Shillong as described by Mr. Dhody was not suitable for adoption in Baluchistan on account of the excessive cost of the wood and on account of the absence of reeds (Sarkanda). The nearest place where reeds were available was Sukkur in Sind. Again walls of Sarkanda plastered over by mud could not give adequate protection against the bitter cold in winter in Baluchistan.

Mr. Malhotra in his enthusiasm for the use of reinforced concrete had forgotten that in members subject to reversal of stress double reinforcement was necessary. In such cases the full use of ccmpressive reinforcement could not be derived without exceeding the safe stresses for concrete. For such members, reinforced concrete construction may not be cheaper than steel.

Further, Mr. Malhotra was probably not aware of the characteristic of the people of Baluchistan when he remarked that a 9-inch brickwall could not offer any resistance to thieves and burglars. There was hardly any theft in Baluchistan. There a whole tribe would form a band of robbers, march upon a village with the beat of drums and plunder every house. Such depredations had, however, considerably decreased in number during the last decade.

Reinforced brickwork recommended by Mr. Malhotra was quite as good as reinforced concrete.

The author informed Mr. Malhotra that the division of India in earthquake zones indicated in Plate I could not but be more or less arbitrary as sufficient and reliable records of the damage done by the past earthquakes in India were not available. Future experience with earthquakes would, perhaps, require wholesale alterations in the map.

The Chairman (Mr. Chopra) thanked Mr. Kumar for bringing out a very interesting paper on a subject on which very little literature existed. It may be said, however, that if not in book form, a good deal of literature dealing with stresses called into play in earthquakes and with earthquake-proof structures has appeared in engineering journals, specially in the *Engineering News Record* of New York. He has collected a good deal of it himself by copying articles from current engineering literature. He is interested in the subject on personal grounds also as he possesses a cottage at Dharmsala, so notorious for its great earthquake of 1905, where he passes his summer so often.