STRIKING BEHAVIOUR OF STRUCTURESIN ASSAM EARTHQUAKES.

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ABSTRACT.

Chapter 1: It is a prevalent practice in Assam to adopt wooden framework for structures in which timber posts are supported from isolated masonry plinth pillars. The structures in which timber posts are fixed in the masonry plinth pillars have suffered badly during earthquakes. Those in which timber posts merely rest on plinth pillars and wherein superstructure is free to move as a whole have behaved well.

Chapter 2: RECOMMENDED MODE OF CONSTRUCTION.

(i) Adopt closed frame construction with horizontal members connecting the columns at foundation level, both in soft as well as in hard strata. The construction generally stabilises the structure, as in a raft, and the horizontal members at the foundation level will prevent the relative ground motion being transferred to the structure.

(ii) For structures founded on hard strata, introduce a medium which will produce discontinuity between the foundation strata and the structure. This will put a limit on the forces and amplitude transmitted from the ground to the structure. In addition to producing effects comparable with damping, it accommodates relative movements of soil particles in the foundations.

Chapter 3: Instances are given which support the possibility of relative movement of soil particles in the foundation.

Chapter 1. REPORTED BEHAVIOUR OF STRUCTURES.

1.1. Assam is literally known as the home of earthquakes. Situated in the North East of India, it is the most unstable region in the country. It is at the foot of the Himalayas which is a young mountain still in the process of formation. All the Indian earthquakes are of tectonic origin caused by the relative movements of blocks in earth's crust along fault planes or by their sudden fracture for relieving of stresses. Assam has been the scene of a dozen of major earthquakes during the last century, including those of 1897 and 1950 which are amongst the severest earthquakes in human history.

1.2. THE COMMON TYPES OF HOUSES

(a) Semi-permenant buildings with plinth of brick masonry walls and

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superstructure consisting of split bamboo walls with plaster and a C.I. Sheet Roof.

(b) Structures consisting of wooden framework, the wooden posts going into isolated masonry pillars forming the plinth. The superstructure consists of split bamboo walls with plaster and a C.I. sheet or thatch roof. There is a clear gap between the natural ground and the ground floor. The height of plinth ranges from a foot or two to 8' or 10', the ground space in the latter case being utilised for garages and stables.

(c) Type similar to (b) above, with the only difference that the wooden posts are not fixed in the masonry plinth pillars, but merely rest on them. The superstructure is free to move as a whole with respect to the foundation.

1.3. REPORTED OBSERVATIONS.

1.3.1. In the report on Dubri earthquake of 1930, Mr. E.R. Gee (6) reports that in the (b) type of structures mentioned in 1.2 irregular oscillations were set up in the structures tending to tear away different parts of the structure from one another, resulting in heavy damage to the structures, whereas the (c) type of structures mentioned in 1.2 escaped damage. Similar observations were reported in the earthquakes of 1934 (17) and of 1950 (16).

1.3.2. Mr.Smith (14) reporting the damage caused by 1897 earthquake describes that every bit of stone work in the neighbourhood of Shillong was levelled to the ground. The only structures of the (c) type mentioned in 1.2 were stables and outhouses and these escaped untouched. Mr.R.D.Oldham (14) who is to be credited with the pioneer study of Indian earthquakes describes that while Government buildings fared badly it was curious to note that the houses of the American Baptist Mission (being of the 'C' type mentioned in 1.2) withstood the shocks with complete immunity. The movements of the framed superstructure relative to some portions in the plinth were measured by the marks on the underside of the frame to be 5".

1.4. DAMAGE TO STRUCTURES FOUNDED ON ROCK.

1.4.1. It has been observed (1) that there was apparently no bearing of damage to structures to the strata on which they were founded and a number of houses whose foundations were on solid rock were damaged while others on alluvium were not damaged.

1.4.2. Milne (13) has cited instances of the New Zealand earthquake of 1931 and the Italian earthquake of 1930 wherein greater damage to structures founded on rock than otherwise was definitely noticed. Mr.J.R. Freeman (5) has also drawn pointed attention to this paradox. Statistical study of earthquake damage in Japan (12) also indicates that rigid frame structures suffer greater damage if founded on rock than if founded on soft strata.

1.5. EARTHQUAKE SHADOWS.

1.5.1. In the report of the Shrimangal earthquake of 1920 (19) attention has been drawn to the extra-ordinary escape of Bharanara and other Tea

Estates owing to their being sheltered by hills. The experience is by no means unusual. Charles Davison (3) has mentioned that where alluvium strata abuts against a hillock, the earthquake wave energy is dissipated at the junction with the result that earthquake damage is precipitated at the foot of hills. A similar observation was made by the author (10) after survey of the damage to the city of Anjar in the Kutch earthquake of 1956, where a part of the town at the foot of a hillock was found to be susceptible to earthquake damage on more than one occassion.

1.5.2. Mr. C.S. Fox (4) suggests that a deep wide trench round an area would shelter the same from earthquake damage. An artificial barrier to precipitate damage with a view to sheltering specific areas from damage looks feasible.

Chapter 2: RECOMMENDED MODE OF CONSTRUCTION.

2.1. STRUCTURES TO BE FOUNDED ON SOFT STRATA.

2.1.1. Based upon the observations regarding behaviour of certain types of structures during Assam Earthquakes, it is proposed to make here certain recommendations regarding the mode of construction to be adopted in general in all earthquake affected areas.

2.1.2. It is recommended that the frame work construction be adopted in preference to structures with load bearing walls.

2.1.3. It is recommended that the framework should comprise of a closed frame, i.e. there should be closing horizontal connecting members at the bottom. Such framework as recommended is depicted in figure 1.a as against framework standing on unconnected foundation legs as shown in figure 1.b. of the customary type. Raft foundation can be said to be a more elaborate form of closed framework construction, the former being represented in the latter as a skeleton.

2.1.4. Even if raft foundation is taken, it is not advisable to form a basement by constructing end walls between the raft and the ground. It would be preferable just to close the gap by an external curtain wall hanging from the plinth beam upto somewhat below ground level; otherwise a clear gap between the plinth and the ground may be left supporting the superstructure on columns as in the case of the Shillong type of construction.

2.2. STRUCTURES TO BE FOUNDED ON ROCK OR ON HARD STRATA.

2.2.1. It is recommended that they should be of framework type and that the foundations of columns should <u>not</u> be thoroughly keyed into the rock, i.e. the columns should <u>not</u> be "fixed" or"encastered" in the foundations. Columns should merely rest on the hard strata in a notch provided in the latter. Some plastic material can close the gaps on the notch which would permit slight movement of the foundation strata with respect to the structure. It would be enough if a latitude of 1/2" to 1" is provided all round the notch for such a movement.

2.2.2. It would be desirable to introduce a layer of accommodating material between the surface of the rock and the bottom of the column. Such insulating layer may be formed of asphaltic concrete, neoprene rubber sheeting or some other suitable material, the purpose of such insulation being to break the continuity of column with the foundation strata and to permit a play between them to a small extent.

2.2.3. It is further suggested that a closed framework be formed even in the case of foundations on rock or on hard strata, as in the case of soft strata (2.1.3.) with the only difference that the closing horizontal members shall not rest on rock, but shall be slightly raised so as to reduce resistance to the movement of the foundation strata with respect to the structure. The construction is indicated in figure 2.

2.2.4. In case one does not like to permit the structure to merely rest on hard strata and desires to provide a positive anchorage in the rock (or in the hard strata), it is recommended to adopt columns 'hinged' at the base as shown in figure 3.

2.2.5. Still another method would be to introduce the accommodating material between the top of R.C.C. column and the plinth beam. The structure would then behave very similar to Shillong type of construction by absorbing the relative motion in the insulating material at plinth level.

2.3. CENTRAL IDEA IN THE RECOMMENDATIONS.

2.3.1. The central idea is to break the continuity or rigidity of the structure with the foundation strata on which it is supported. The discontinuity will in the first instance considerably reduce movements and shocks transferred to the structure, the insulating material acting as a buffer. In addition it will also permit differential movement, if any, between the soil under different portions of the structure.

2.3.2. The closing members at the bottom act as braces at lower levels and interconnect the foundations. Any forces that are produced by the differential ground movement during the shock are overcome as direct forces of compression and tension in the closing members, and are prevented from creating undesirable stresses due to heavy bending moments and shears. As a result, motion transmitted to the structure shall be a sliding or a rocking movement of the structure as a whole and there will be no tendency for different parts of the structure to tear or shear away from one another.

2.4. STATIC EFFECTS OF EARTHQUAKES ON STRUCTURES.

2.4.1. It would be instructive to study the static and dynamic effects of earthquakes on structures . Such a study will reveal the difference between the expected behaviour of the recommended types of structures and the customary ones.

2.4.2. The forces on account of earthquakes which need consideration are as under:

(a) Equivalent static effect, (b) Dynamic effects and (c) effects due to differential ground movement.

2.4.3. The effect of sudden movement of the ground on the structure is equivalent in magnitude to the effect of the inertia force on the structure produced by the acceleration with which the ground is moving at any instant. These forces are commonly taken into consideration in all designs; certain aspects of such forces are dealt with presently.

2.4.4. When the ground on which a structure stands starts moving, say with an acceleration α, this acceleration is transmitted to the strudture through and on account of the continuity of the structure with the ground. Having no continuity with the ground, an aeroplane flying in the air will not suffer any acceleration due to ground shocks. As long as the continuity between the foundation and the structure is maintained, the lateral force operative on the structure of mass M is $M\alpha$, and the acceleration produced in the structure (α') is the same as α. If the bond resistance or the frictional resistance between the ground and the structure (F) is less than $M\alpha$, sliding between the two takes place, and in that case the lateral force operative on the structure does not reach the full value of $M\alpha$, but is limited by the value of F. The acceleration of the structure α' that would be produced when sliding between the ground and the structure takes place is the acceleration which a force F would produce on a mass M. F, the resisting force of sliding friction is equal to $\mu M g$ where μ is the coefficient of friction; the acceleration in the structure would then be

$$\alpha' = \mu \cdot g \qquad \text{.... (1)}$$

For calculating the actual acceleration and forces on different parts of the structure the appropriate reductions for damping and amplifications for increased heights etc., will have to be considered in addition.

2.4.5. The author in a paper written jointly with Mr. S.B.Joshi (11) has shown that friction between two surfaces comprises of resistance to work against gravity in riding over irregularities, and, or resistance in shearing off the irregularities. When structure is founded on soft material, the frictional resistance is replaced by the shearing within the soft material and is equal to S.A, where S is the shearing resistance per unit of Area and A is the area of shearing. Thus in such a case the force transmitted to the structure $F = SA = M\alpha'$. The effective acceleration produced in the structure will then be $\frac{SA}{M}$

$$\alpha' = SA/M \qquad \text{... (2)}$$

2.4.6. The expressions for acceleration derived in 2.4.4. and 2.4.5 are significant.

α' the acceleration of structure = acceleration of the ground α
and is limited by $\alpha' = \mu \cdot g$ .... (1)

or $\alpha' = \frac{S\,A}{M}$ .... (2)

Acceleration in equation 1 is independent of Mass, while that in equation 2 is inversely proportional to the Mass of the structure. It can, therefore, be concluded that as far as resulting forces and accelerations on the structure are concerned, increased Mass or inertia of a structure is definitely helpful in the case of foundations in soft strata, i.e. where equation 2 applies.

Of course the increase of mass should not be such as to add to the debris in case of failure, for very often the damage to life and property arises more out of the debris than anything else.

2.4.7. Prof. Suyehiro (20) has shown that 'by reason of its inertia, the movement of a rigid building on a massive foundation may be much smaller than that of sand or mud on which the foundation rests. Soft yielding sand or mud sways to and fro beneath the foundation without imparting to it vibrations of large magnitudes'. The view confirms observations in 2.4.6. When the maximum force transmitted to the structure is determined by S.A, as in equation 2, the fill on the raft artificially increases the effective mass of the structure as a whole and hence reduces the acceleration of the structure. The fill on the raft, however, does not increase the effective force producing stresses in the framework of the structure, but on the other hand decreases the effective force by reducing the impressed acceleration.

Further the raft distributes the load on a large area, makes the structure bottom heavy, adds greatly to its general stability and permits rocking and sliding of the structure as a whole. All these benefits make a raft a very effective construction against earthquake damage. A closed frame structure inherits the above benefits, some partially and others to the full extent.

2.4.8. At the same time that the raft increases the effective mass, it also increases the base area A. Thus according to equation 2, increase of A increases α', while increase of M reduces α'. Perhaps a closed frame structure as recommended herein strikes a good mean. Actually it has an advantage over a raft in that the former has less base area and transfers less lateral force to the structure than in the case of a raft. A raft without a fill over it, as in the case of a basement, would, however, be a positive disadvantage, as it would increase the lateral force transmitted to the structure (S.A), without increasing the mass and hence without reducing the acceleration on the structure. In addition the side walls of the basement expose large area of obstruction to earthquake waves. This substantiates 2.1.4.

2.4.9. As shown earlier, the basic maximum acceleration produced on a structure during an earthquake is less than the maximum ground acceleration. The actual motion of the ground, it is known, is complex. The actual motion of the base of the structure is still more complex in view of the fact that the instantaneous acceleration of the structure is not only dependent on the instantaneous ground acceleration but also on the relative velocity between the two. It is to be expected that with the reduced maximum acceleration of the base of the structure, its maximum amplitude and its average velocity will be less than the corresponding values for the ground motion. The effect of the reduced maximum amplitude of the base of the structure is dealt with in 2.5.2.

2.4.10. If V is the average velocity of soil particle during a dominant wave in an earthquake, the energy input of the structure is $MV^2/2$. The energy is dissipated in several ways such as damping and in causing the elastic and plastic strains in the material of the structure. If the energy input is beyond what the structure can bear, some dissipation of energy takes place in cracking and in causing other damage. Now if during the transmission of motion from the ground to the structure, sliding between the ground and the structure (2.4.4.) or shearing in the foundation material (2.4.5.) takes place, the average velocity transferred to the structure is less than the average velocity of the ground (2.4.9.). The energy transferred to structures provided with discontinuity as recommended is therefore less and consequently less in the chance of damage to such structures.

2.5. DYNAMIC EFFECT OF VIBRATIONS.

2.5.1. The natural period of vibration of a structure considered as a shear column depends upon the end condition at the base, and will be much larger if the base is hinged rather than fixed in the ground. Study of earthquake spectra shows that response base shear of a building decreases almost inversely with its natural period. Moreover higher natural period reduces the possibility of synchronization of dominant period waves.

2.5.2. The deflections from vertical position, bending moment and shear produced at different altitudes in a structure are all direct functions of the maximum amplitude of vibration at the base of structure (2). The discontinuity between the ground and the structure reduces the amplitude of vibration during its transmission from the ground to the base of the structure. The discontinuity in recommended construction therefore results in reducing the deflections from the vertical, bending moment and shear at different altitudes of a structure during strong ground motion.

2.6. EFFECTS DUE TO DIFFERENTIAL GROUND MOVEMENT.

2.6.1. In addition to the effects on the structure as a whole, it is necessary to consider the effect of differential movement below two neighbouring columns of a structure. The question about the possibility of such differential movement is discussed in Chapter 3.

2.6.2. With a view to simplification forces on a portal frame are considered here. The inferences will be applicable to rigid framed structures in general. Three cases will be considered, namely, when the frame is (a) fixed, (b) hinged or (c) sliding on the ground. It is assumed that the ground at the supports is moving and that there is a relative horizontal displacement Da, Db and Dc respectively in the plane of the frame. It is furtherassumed that the moment of inertia and length of all the members of the portal frame is the same.

(a) Portal frame fixed in the ground (figure 4a)

$$\text{Bending Moment} = \frac{2EI}{L^2} \cdot Da \qquad \ldots (3)$$

$$\text{And shear} = H = \frac{3EI}{L^3} \cdot Da \qquad \ldots (4)$$

(b) Portal frame hinged to the ground (figure 4b)

$$\text{Bending Moment} = \frac{0.6\ EI}{L^2} \cdot Db \qquad \ldots (5)$$

$$\text{And shear} = H = \frac{0.6\ EI}{L^3} \cdot Db \qquad \ldots (6)$$

(c) Portal frame with sliding supports, the resistance to sliding being F when sliding begins (figure 4 c).

$$\text{Shear} = F \qquad \ldots (7)$$

$$Dc = \frac{5}{3} \cdot \frac{FL^3}{EI}$$

$$\text{Bending Moment} = FL = \frac{0.6\ EI}{L^2} \cdot Dc \qquad \ldots (8)$$

Values of Dc and F are not more than the values of Db and H, the corresponding values being equal till the sliding in (c) takes place.

Bending Moments and shears in the three cases depend upon the moment of inertia and length of members; but the results obtained above are indicative of the influence of base conditions on the same.

It will thus be seen from equations 3 to 8 that columns with hinged bases will produce less severe stresses than columns with fixed bases. However, columns with sliding bases will produce still less stresses, their maximum being equal to the case when the columns are hinged.

The equations also explain the paradox that R.C.C. riged framed structures are safer when founded on soft strata than when founded on rock, for in the former case equations 1,2,7 and 8 operate whereas in the latter case equations 3 and 4 operate.

2.7. CORROBORATION WITH RESULTS.

2.7.1. In the foundations of some tall structures it is a practice in the United States of America to introduce a 3 feet layer of gravel between foundation rock and the structure (2). The purpose of such layer is to break the continuity between hard foundation strata and the structure. The practice confirms the principle of the recommendations stated in 2.3. The hinged condition at the base also helps to increase the natural period of frequency of the structure.

2.7.2. Mr.Jacob J.Creskoff (2) has recommended the adoption of inter-connected foundations, where raft foundation is prohibitive in cost. This is in confirmity with the recommendations made herein.

2.7.3. Behaviour of the Shillong type of structuresin Assam have well exemplified the immunity of such type of construction, i.e. of structures which were not fixed to the ground but were free to move as a whole. The recommendations made in this paper are merely the extension of the principle.

2.7.4. Raft construction is almost universally recommended and has yielded splendid results. As mentioned in 2.3.1. raft is merely an elaborate form of a closed framework type of construction; whatever applies to a raft applies to a closed frame structure.

2.7.5. To illustrate the point, it may be well to give some parallels from daily observations. A table or a stool with legs connected near the base behave well in dragging and shaking. So also does a box.

The heavy forces of nature are best tackled by curbing them than by total obstruction. Tiny weeds can stand a flood better than a stout tree.

Chapter 3. DIFFERENTIAL GROUND MOTION

3.1. SURFACE WAVES.

3.1.1. Differential ground motion within the area occupied by a structure due to passage of Primary and Secondary waves would be too small to affect the structure, because of the high magnitude of wavelengths of such waves. From the point of view of differential ground movements, surface waves are important.

3.1.2. Though surface waves were first predicted theoretically by Poisson as early as 1829, and more elaborately explained by Rayleigh in 1887, it was not till 1900 that various types of surface waves were analysed by actual records due to the distinguished work of R.D. Oldham on Assam Earthquakes. It was observed in Assam Earthquakes that the rice crop was falling and rising, as the waves passed, their speed though being decidedly faster than what a man could walk was not as fast as he could run. Mr.Oldham estimates the wavelength to be 30 feet and the height of waves as one foot (14). During the 1811 earthquake in the Central Mississipi area, the ground was observed to undulate in waves several feet high and the depressions between successive waves were clearly visible (9). During the Charlestone earthquake of 1886 in South California, waves about 2 feet high were observed moving rapidly and shadows cast by successive wave crests could be seen distinctly in the gas light. 'One of the most alarming and disastrous features of a great earthquake near its place of origin', observes Arthur Holmes (8), 'is the passage of large surface waves over the ground which is thrown into overchanging undulations'. F.Kingdon Ward, a western traveller, who was caught in the Assam earthquake of 1950 gives a very vivid description of the movement he experienced saying that the solid mountains were in the grip of a force that was shaking them as a terrier shakes a rat. (21).

3.2. DISPLACEMENT OF OBJECTS.

3.2.1. Displacement of objects during earthquakes leaves no doubt of the differential ground motion involved. A few illustrations are given. It might be noted that some of the observations are at fairly distant places from the epicentre being in isoseists nos.3 and 4, indicating that differential ground movements takes place over a vast area.

3.2.2. An extremely interesting case has been reported by Murray Stewart (19) while reporting on the Shrimangal earthquake of 1920. At Kishoreganj in isoseist no.3 was a stack of loose bricks about four feet wide and five feet high, 120 feet in length in the North South direction. The bricks had fallen in places along the western face of the stack, not all the way along the face, but at definite intervals, there being a space of 31 ft. unfallen between the two consecutive points where bricks had fallen. A possible explanation for equal intervals of 31 ft. between spots of disturbance is the formation of nodes and antinodes due to the combination of two simultaneous waves arising from the sympathetic shocks off Madras and Arakan reported during the said earthquake which having components in the same direction must have caused maximum displacements at points where the two waves strengthen each other. Alternatively formation of antinodes may be due to some local reflection and refraction. In the Charlestone earthquake of 1886 in South California (9), surface ground waves were reported to be crossing others diagonally and giving the effect of a chopping sea. The action on the stack of bricks appears similar. Whatever the explanation, the fact of loose bricks not falling all along but only at certain spots indicates that movement at different places though near to each other are different.

3.2.3. At Gourigram in Isoseist no.4 of the Shrimangal earthquake (19), two sides of a triangle of a railway line used as a turntable were considerably bent, one rail being found to have a curvature equivalent to a radius of 30 ft. The base of the triangle was at right angles to the the direction of the wave and was not affected. Bending of rails has in fact been very frequently observed.

3.2.4. Reporting on the Cachar earthquake of 1869 (15), Mr.Oldham describes that a Hindu temple under the shelter of a banyan tree was quite uninjured in the neighbourhood of a well-built jail wall which lay in ruins. Oldham explains the miraculous escape being due to the binding effects of the wide spread roots of the tree which tied the whole ground together. This instance indicates the protection from damage by preventing differential ground motion.

3.2.5. Oldham reports of relative displacement of two parallel tombs at Cherrapunji in the earthquake of 1897. The visible signs on the ground indicated that both the tombs had shifted towards each other, one by 18" and the other by 10".

3.3. ROTATION OF OBJECTS.

3.3.1. Several observations of rotation of objects have been reported in Assam Earthquakes. A few notable instances are given below:

3.3.2. A billiard table at Lalchand Tea Estate rotated through a few inches in the clockwise direction (19). At Luskerpore Tea Estate vertical flat irons of the frames of the leaf house were twisted. In isoseist no.3 Langla Marager's bunglow a 400 day clock which was facing East and standing on the top of a whatnot rotated in a clockwise direction and came to rest facing North. An iron safe facing West was jerked out towards the west and was left facing North West.

An obervation of special interest reported by Oldham is the rotation of all the eight columns of an octogonal thermometer shed at Dubri, everyone rotated round its own vertical axis in the clockwise direction through an angle varying from 5 degrees to 12 degrees.

3.3.3. Pillars and monuments being supported on a single base, without any branches or overhanging projections are simple structures which would involve the least possible complication of stress conditions. Acting almost like a pendulum they keep a faithful register of forces coming into operation during earthquakes. Where instrumental observations are lacking they can be a valuable source of information.

3.3.4. Some very interesting observations have been reported by Oldham.

In a monument to George Inglis at Chhatak rising to a height of 60 ft. from a base of 12 ft. square, the topmost 15 ft. of the pillar was thrown off and the block of the next 22 ft. height had twisted through 30 degrees in the anti-clockwise direction. The section of the pillar at the plane of rotation was 9 ft. square. During rotation, the twisted portion had shifted 1'-2" towards N 55° W.

At Cherrapunji out of two pillars standing close to each other, one twisted anti-clockwise through 5 degrees while the other twisted clockwise through 4 degrees. At Shillong, a gate pillar of Fernadale Hotel turned anti-clockwise on its base through 4 degrees and again above the lowermost stone through another 2 degrees. A tomb pillar at Gauhati was broken higher up and had twisted clockwise through 48 degrees. Mr. Gill recorded during Dubri earthquake twisting of the topmost three feet of a fifteen feet high pillar through 20 degrees.

Opposite twisting of neighbouring pillars has been reported in some cases and is likely to be thought as baffling. Such opposite rotation was also reported of two obelisks standing side by side in the Calabria earthquake of 1783.

3.3.5. Millet, Gray and Oldham tried to explain rotation of pillars, each in his own way; but the common tune appears to be that changing of directions in rapid succession results in lifting of the centre of gravity slightly on one edge and being pulled in another direction in the meanwhile. This suggests a sort of vertex motion or some complex combination of S.H.M. for individual soil particles. The possibility of such complex combination of simple harmonic motion of individual particles can be conjectured by superimposition of N-S, E-W and V-H seismograms of a point vibrating under a strong ground motion.

3.3.6. A vortex motion or a complex combination of S.H.M. of individual soil particle explains the rotation of bodies, twisting of monuments as also the twisting of all the eight columns of the thermometer shed (3.3.2). It is further to be appreciated that the simultaneous rotation or twisting of two points each about its own vertical axis implies a combination of rotation about a common axis and a differential motion of translation between the two points.

3.4. SEISMOGRAPHIC DATA.

3.4.1. The seismographs of different stations in the town of Yakohama have not produced identical seismograms with a short time lag for the same earthquake (12). This proves that actual ground motion at two places within a short distance of each other differs considerably, i.e. so to say the differential movement between them does exist.

3.4.2. As a matter of fact, installation of seismographic instruments has to be done well below the ground surface, so that erratic movements at the surface are eliminated. Thus at very shallow depths of say 4' to 8' where foundations of several structures may be founded, differential soil movement is more likely to prevail than not.

3.5. GROUND UPHEAVELS DURING EARTHQUAKES.

3.5.1. Ground upheavels and depressions over a considerable expanse of land and water during earthquakes have been observed. After a lot of survey operation after the Assam earthquake of 1897, Mr. Bond found that heights of stations had risen by amounts varying from 6' to 24' and in one case there was a subsidance of 4'. A horizontal displacement of several feet of vast area was brought about during the earthquake. The greatest throw of the chedrang fault reported in Assam was 35 ft, the greatest ground uplift ever recorded was during the Alaska earthquake of 1899 where the coast was elevated by 47'-4" at one point. One of the largest submarine movements on a slope West of Greece in 1893 raised the sea bed from 1600 to 2300 ft.

3.5.2. With such heavy and expansive ground movements during earthquakes, relative movements cannot be ruled out of possibility.

3.6. GENERAL.

3.6.1. There is little doubt that the nature of the strata immediately below the surface greatly modifies the amplitude and speed of surface undulations (4). The seismograms at three stations within 1 Kilometer distance of each other in Tokyo (12) confirm the above statement. Because of the complex nature of earthquake waves and the heterogeneous character of the earth, the movement of a particle during an earthquake is extremely complex (18). A differential movement of soil particles within short distances is therefore to be expected.

3.6.2. The above illustrations and discussion strongly suggest the possibility of differential ground motion in foundations. It is therefore necessary to take them into consideration in designing earthquake resistant structures and also to take steps to counteract the same.

It is submitted that the recommended mode of construction takes full notice of such differential ground movements.

CONCLUSION

Reference is invited to the abstract

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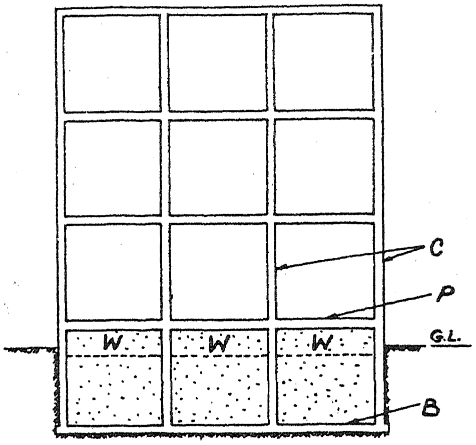
NOMENCLATURE.

A	Area of shearing.
Da	Horizontal deflection of the portal frame, when fixed (fig.4a)
Db	Horizontal deflection of the portal frame, when hinged (fig.4b)
Dc	Horizontal deflection of the portal frame when supported on roller (figure 4c)
E	Modulous of Elasticity.
F	Force of resistance to sliding.
g	Acceleration due to gravity.
H	Horizontal pull on the frame when fixed or hinged.
I	Moment of inertia.
L	Length of the vertical member of the portal frame.
M	Mass of the structure.
S	Shearing strength per unit area.
V	Average velocity of soil particle.
α	Max.Acceleration of ground during an earthquake.
α'	Max.Acceleration of the structure during an earthquake.



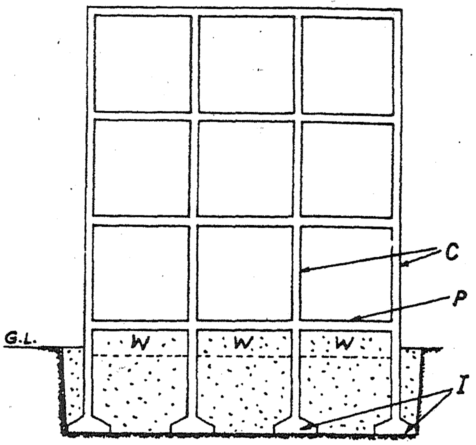
B: BOTTOM CLOSING MEMBER OF FRAMEWORK.

C: COLUMNS.

P: PLINTH BEAM.

W: CURTAIN WALL HANGING FROM PLINTH BEAM.

FIG. 1a (REF. 2.1.3.)



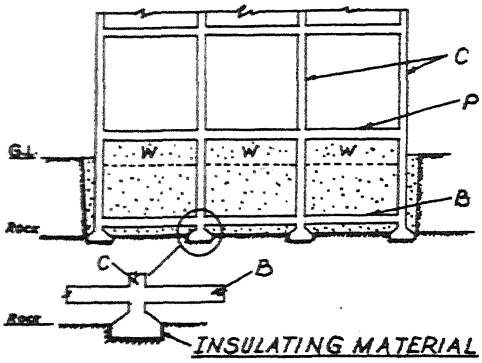
C: COLUMNS

I: ISOLATED FOUNDATIONS OF COLUMNS

P: PLINTH BEAM

W CURTAIN WALL HANGING FROM PLINTH BEAM

FIG. 1 b (REF. 2.1.3)



B: BOTTOM CLOSING MEMBER OF FRAMEWORK

C: COLUMS

P: PLINTH BEAM

W: CURTAIN WALL HANGING FROM PLINTH BEAM

FIG. 2 (REF. 2.2.3)

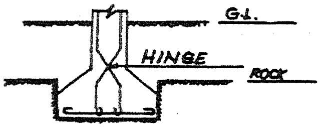


FIG. 3 (REF. 2.2.4)

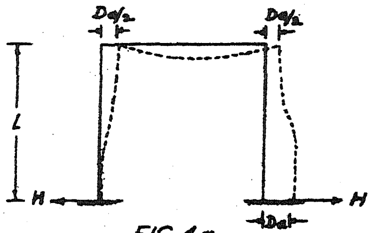


FIG. 4a

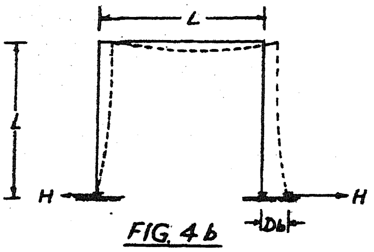


FIG. 4b

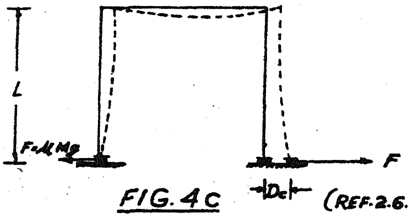


FIG. 4c (REF. 2.6.2)