Field experience section

SIMULATED EARTHQUAKE TEST OF A TIMBER HOUSE

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1. Introduction

As their product is being erected in many areas prone to earthquake, a New Zealand building company decided to investigate the effect of earthquakes on one of their units constructed at Rotorua. Recommendations which had been made by the D.S.I.R. on the nature of the tests were followed but were extended to give a more comprehensive set of tests.

2. Discussion

As earthquakes consist of random ground movements over a band of probable frequencies, it was considered necessary to apply a range of exciting frequencies to the house under test. Because the majority of the damage done by earthquakes is attributabl to the horizontal movement only, the expense of simulating vertical motion was not considered justifiable.

3. The House

The house tested was a 1,000 sq. ft. unit built of Pinus Radiata (Fig. 1). Exterior walls were 2 5/8 in. thick, tongue and grooved planks, stacked horizontally and aluminium sheathed. Provision was made for additional vertical tie rods in the interior 1 3/4 in. thick partitions. These were used in the initial tests and dispensed with (by loosening the nuts under the floor on the ends of these tie rods) when it was found that they were not required. The dividing partition between kitchen and lounge was only 6 ft. 10 in. high, and there was no partition between kitchen and dining room. The roof cladding was light gauge metal tiles. The house was supported on top of 8 in. square concrete blocks, which were lying on their side on a concrete slab (Fig. 4). Movement of the house at floor level was restricted, but not fully restrained, by timber props around the perimeter (Fig. 5).

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4. The Earthquake Simulator

A 1 3/4 in. thick timber ceiling was built in the entrance hall to support the earthquake simulating mechanism, which consisted basically of a 10 HP motor driving a centrally pivoted 6 ft. 10 in. long arm, which rotated in a horizontal plane close to the underside of the roof in the centre of the house. By bolting weights to the arm at various distances from the centre of rotation, a variable out-of-balance centrifugal force was generated, which was transferred to the walls of the house through the sarking (roof decking) from the steel framework of the earthquake simulator. The frequency of the out-of-balance centrifugal force was altered by changing the size of the pulleys on the rotating shaft.

5. Preliminary Calculations

The centre of gravity of the house was found (vertically and horizontally) so that the earthquake simulator could be fixed as close as possible to that position. Shear stiffnesses for all walls and components were calculated on the assumption that the walls would behave as solid timber walls (in fact, this did not occur, and the actual deflections measured were much greater than those calculated, due to the sum of all the horizontal movements which occurred between adjacent planks). The shear centre of the building was calculated and, as it was reasonably close to the centre of gravity, torsional effects were disregarded. Attempts were made to estimate the fundamental natural period of the building and the level of the exciting force was adjusted (allowing for dynamic magnification) to limit the induced forces in the building to about 0.6 gravity at any level in the resisting walls.

The rotating arm, shaft and bearings of the earthquake simulator were designed to have adequate safety factors for the loads applied to them.

6. Records made of Tests

Recording devices were fixed to the four corners of the building, so that a permanent trace of the movement at floor level and at roof level was obtained during each test. The position of door frames, window frames and corner posts and the fit of doors and windows were noted before and after the tests.

A series of tests was made, the first six at 8.7 cycles/sec. (Fig. 3), with progressive increments in the out-of-balance force. The internal ties were loosened off for the last two tests in the first series and no noticeable increase in the movement of the house was observed. These were followed by a second set of five tests which vibrated the building (without the internal tie rods) at different frequencies.

7. Observations made during Tests

Shear deflections at eave level of up to 5/8 in. horizontally were recorded at 5 cycles per second, with an out-of-balance centrifugal force of 5,630 lb. The weight of the entire building was estimated to be 33,500 lb. (including the floor), and the roof and upper 2/3 of the walls were estimated to weigh 20,500 lb.

During the tests, window frames and wall sections vibrated and creaked in an alarming manner but no residual damage could be detected. All windows and doors continued to work satisfactorily at the end of all the tests. It was noted that the props around the perimeter of the building at floor level did not fully restrain the building, so that during the final tests, movement of up to 3/16 in. at floor level was recorded. This resulted in a system of two degrees of freedom, each system having its own basic resonant frequency.

(The power consumption for the motor was measured as 32 amps/phase when rotating 32 lb. at 8.7 cycles/sec, on a 31½ in. long arm - c.f. the continuous power rating of the motor of 14.7 amps/phase.)

8. Results

The frequency/amplitude curve (Fig. 2) was plotted for an exciting force equal to 20% of the total weight of the building tested, including the floor. From this graph, the effects of the second degree of freedom appeared to be more significant at the higher frequencies, i.e. as the speed of the rotating are was increased, the concrete blocks started to rock at ground level.

9. Summary

It must be recognised that a real earthquake consists of a series of random pulses, where as the tests consisted of a regular cyclic force. While it is possible that some residual deflection might result under a real earthquake test, this would tend to be less than the maximum deflections which were recorded during the test. The nature of the construction is such that these deflections are easily accepted without causing secondary damage to finishes, which would make repairs necessary or make the house unusable.

It was considered that the series of tests covered the range of known frequencies of the ground motion, and simulated the level of ground accelerations that records show can be expected in earthquake zones. In addition, the tests were carried out with a range of frequencies which would ensure that the maximum response was generated in the building. The forces induced in a building in an earthquake depend, amongst other things, upon the distance of the building from the epicentre. In the tests it was attempted to simulate conditions that would develop in the region close to the epicentre of an earthquake of the order of 6 to 7 on the Richter Scale, which would produce observed damaged levels on the Modified Mercalli Scale of 8 to 10 for a conventional wooden framed house.

10. Conclusion

The tests indicate that the house tested was well suited for use in earthquake prone areas. A tendency observed for even the low foundations to rock under earthquake tests, demonstrated the need for stable, well constructed foundations for any house, and bears out the observation that isolated pile foundations are an unsuitable form of foundation for houses in earthquake zones.

11. Acknowledgements

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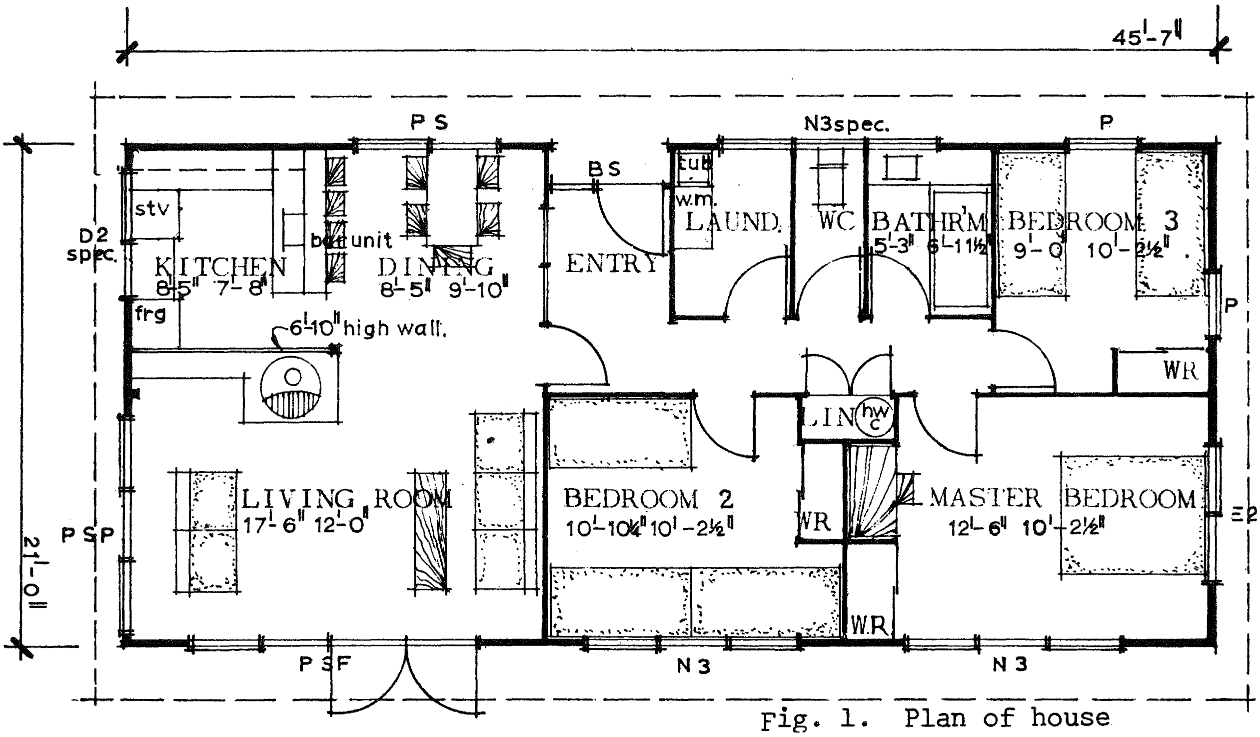

Fig. 1. Plan of house

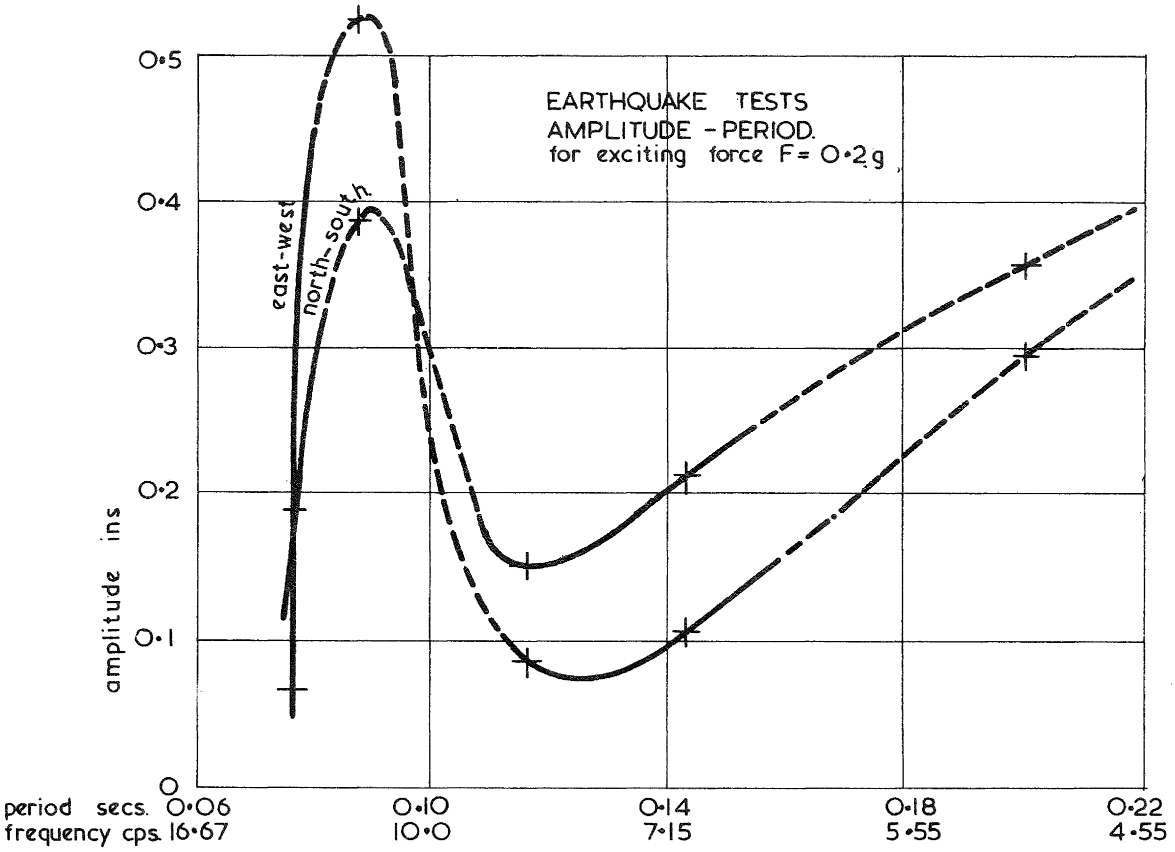

Fig. 2. Variation of amplitude with period of excitation

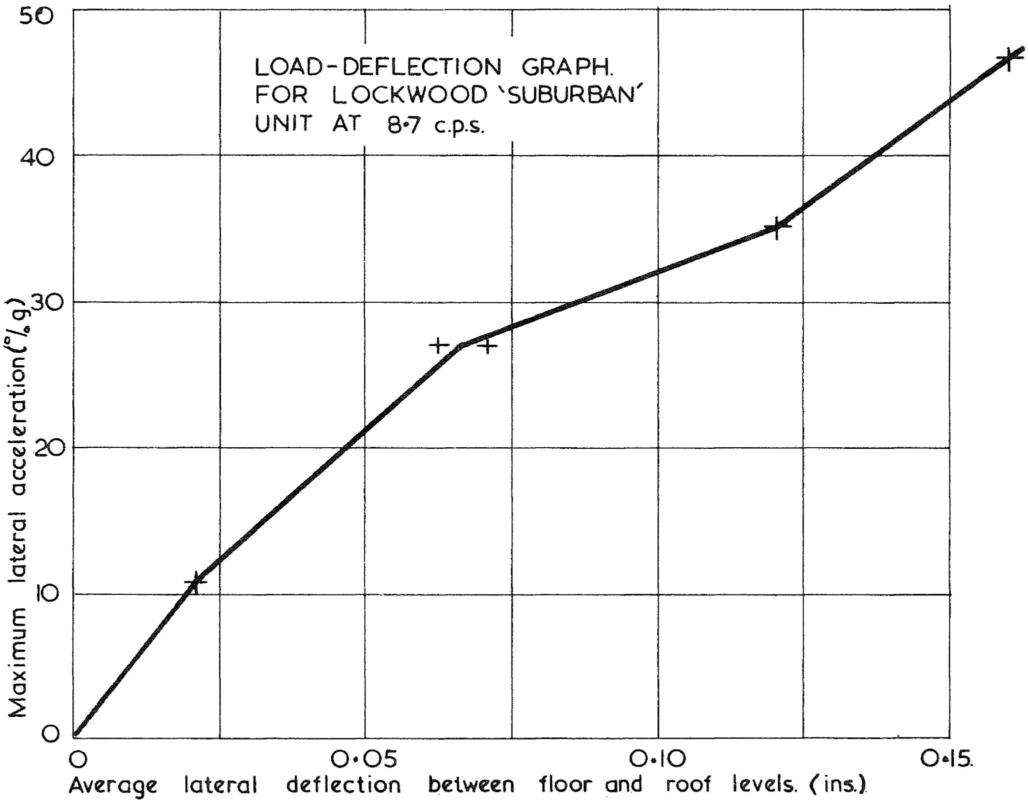

Fig. 3. Relation of load and deflection, at 8.7 cycles/second