SIMULATED EARTHQUAKE VIBRATION TESTS ON BRICK MASONRY MODEL THROUGH CONTAINED UNDERGROUND EXPLOSIONS

Qaisar Ali*, Akhtar Naeem*, and Siddique Akbar**

ABSTRACT

The paper describes details of simulated earthquake vibration generated through contained underground explosions. The tests were carried out on single story unreinforced masonry model as part of the PhD work of the first author. The testing activity included total of three explosion tests. The explosion in test 1 was conducted for evaluating the dynamic characteristics of the masonry model. Explosions in tests 2 and 3 were carried out with increased intensity for determining seismic resistance of the masonry model. The paper concludes that generation of simulated earthquake vibrations through contained underground explosions can be effectively used as a substitute to other costly method of dynamic testing of structures.

INTRODUCTION

Several experimental techniques have been used in the past for dynamic testing of structures. These include static monotonic, quasi-static (slowly reversed cyclic), pseudo-dynamic tests using shake table (earthquake simulator). Other alternatives are impact table and excitation of soil through underground explosions. Each method has its own merits and demerits. For example static tests have the advantage of continuous monitoring of the models but investigations have shown that their results can widely vary from the dynamic test on similar model. High performance seismic shake tables are capable of simulating real earthquake events but have the handicap of being very costly. Studies on use of impact table have shown large differences between the structural response to impact loading and continuous ground motion.

Short of waiting for an actual earthquake to occur, the use of underground explosions is probably the only means for reproducing earthquake like ground motions in a field environment. Considering that the soil-foundation interface and soil-structure interaction are important aspects of seismic response, testing in a field environment has considerable advantages. Ground motion obtained from firing a single charge produces large accelerations but small velocity and displacements. The generated motions resemble parts of a seismic ground motion that is severely compressed in time and equally exaggerated in acceleration. It appears to be feasible to use this technique for field testing of models. This technique becomes more attractive if it is considered that a series of closely spaced pulses can be generated by setting off synchronized charges in a series of line sources.

DESCRIPTION OF STRUCTURAL MODEL

Single story isolated room consisting of 16’ x 13’ plan dimensions (center to center) and 14’ height was subjected to simulated earthquake vibrations produced through underground explosions. Walls were named A, B, C and D. Wall D had two openings whereas the remaining three walls were solid. Fig 1 shows plan of the model and sectional elevation of wall D. Fig 2 shows overall view of the site. The ground of the site comprised firm soil deposits.

MATERIALS AND METHODS OF EXPLOSIONS

1. Explosive Materials

The explosive materials consisted of detonating cord, safety fuse, detonator, nitroglycerine based explosive called S-3 seismic explosive and non electric initiation system (delays).

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Detonating cord, supplied in the form of 250 meter PVC coated reel, consists of a core of high explosive contained in polythene and wrapped in various layers of cotton/jute yarn. Its velocity of detonation is 6000-7000 m/sec with explosive gramme of 10 g/m.

Safety fuse, also supplied in the form of 250 meter PVC coated reel, consists of a central core of specially formulated black powder with jute and cotton counteracting. It is designed to propagate flame to the plain detonator within specified time limits. Its burning time is 100-120 sec/m.

Standard type Plain Detonator, supplied in the form of 41 mm long and 7 mm round aluminum casing consists of a base charge of high explosive and a primer charge of an initiating explosive pressed into an aluminum tube.

The S-3 seismic explosive is cartridge in specially designed high density, rigid, 2.5 inch diameter, 18 inch long plastic tubes containing 1 Kg gelatin type nitroglycerine based explosive. The tubes can be coupled to one another make the desired length of column of charges.

Special non electric initiation system (delays), available in 5, 10, 15, 20 and 25 meter length and rendering delay time from 25 milliseconds up to 1 second, were used for firing an array of line charges with certain interval.

2. Explosion Tests—Objectives and Arrangements

The simulated earthquake vibration tests through tests through contained underground explosions were carried out on brick masonry to achieve the following objectives:

(i) To determine the dynamic characteristics of the brick masonry model; and

(ii) To determine the seismic resistance of the model

3. Data Acquisition System

Piezoelectric type accelerometers with a recording range of ±10g were used for recording accelerations during tests. The accelerations measured by the
accelerometers were amplified by the charge rate of 0.5 v/g.

4. Testing Methodology

Prior to commencing actual testing operation, several small trial explosions were carried out in the nearby site to finalize design scheme for actual explosion tests. The trials were made by changing the depth, size and distance of explosive from the object. After a thorough study of the trial tests, total of three tests were carried out in the following way to achieve the objectives.

5. Explosion Test 1

(i) Explosion design: Test 1 was designed with the objective of evaluating the dynamic characteristics of the masonry model. The explosive was placed in 4 inch diameter bore holes drilled to a depth of 15 ft. The schematic view of explosion design for test 1 is shown in Fig 3. Walls are named A, B, C and D. As already shown in the model layout, wall D has two openings whereas all other walls are solid. The axes directions along longer and shorter walls are named as X and Y respectively.

(ii) Sensor’s positions: Total eight sensors were installed on the model. Three sensors each were installed at the base, middle and top of walls A and B to record horizontal acceleration. The base and the middle sensors were mounted on bricks directly and the top sensor was installed on the part of the roof slab resting on the walls. Fig 4 shows sensors installed on wall A. Similar arrangement was followed for wall B. One sensor each was installed at the top of roof (center of slab) and base of wall D (above Damp Proof Course in the door opening) for measuring vertical accelerations, Fig. 5.

(iii) Accelerometers record: The data was recorded at the rate of 100 samples per second. All the acceleration records were low pass filtered at 20 Hz. The acceleration time history record of all the sensors for test 1 is given in fig 6. Figs 6 (a) and (b) show uncorrected accelerograms for base, middle and top sensors along X and Y axes respectively; whereas figs 6 (c) and (d) show uncorrected vertical acceleration time histories for base and top of the model.

To determine fundamental period of the model along X and Y axes, the PSD plots of model top acceleration along X and Y axes were drawn, Fig 7 (a) and (b). Damping ratio of the model was determined from half power band width and logarithmic decrement of the free vibration part of the accelerograms. Table 1 shows summary of the results obtained from test 1.
6. Explosion Test 2

(i) Explosion design: The schematic view of explosion design is shown in Fig 8. The holes were fired from hole 1 to 2 with 250 millisecond delay to increase the duration of shaking. The explosion was designed such as to produce simulated earthquake vibration in both X and Y directions simultaneously, a severe case of earthquake. Explosion activity during test 2 is shown in Fig 9.

(ii) Sensor's position: Sensors' position for test-2 was the same as test-1. Unfortunately, due to unforeseen reasons, the data of only three sensors could be successfully obtained in test 2.

(iii) Accelerometers record: The uncorrected accelerograms along X direction for model base and top and along Y axis for model only are given in Fig 10 (a) and (b). The two peaks at an interval of 0.25 second are very clear in the figs, notifying initiation of explosion from hole 1 to 2 with a 250 millisecond delay. No reliable data could be obtained from the remaining sensors. Peak Ground and Response Accelerations along X and Y axes for test 2 are given in Table 2.

Fig. 6. Acceleration time histories for TEST 1.

Fig. 7. PSD plots for model top accelerations along X and Y axes.
Table 1: Summarized Results of Test 1

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Peak Ground Acceleration along X-axis</td>
<td>0.1487g</td>
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<tr>
<td>Peak Response Acceleration along X-axis (model top)</td>
<td>0.2382g</td>
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<td>Amplification factor</td>
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<td>Natural Period of the model along X-axis (longer walls)</td>
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<td>Peak Ground Acceleration along Y-axis</td>
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<td>Natural Period of the model along Y-axis (shorter walls)</td>
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<td>Damping ratio of the model</td>
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(iv) Effects on model: Damage to the model is shown in Figs 11 (a) to (d). As expected the dominating mode of failure was in-plane shear. The sliding of lintel along the length of wall, a type of shear sliding failure is visible in Fig 11 (d).

Walls A, C and D have suffered typical shear cracks (characteristic diagonal cracks) which are instantly recognizable in Figs 11 (a), (c) and (d).

Examining the effects on wall C, Fig 11 (c) in combination with Fig 8 (explosion design), it is clear that wall C was closest to holes. The wall cracked both in in-plane shear as well as out-of-plane bending modes. The horizontal cracks (parallel to the length of the wall) at the center of wall C are typical out-of-plane bending cracks due to maximum positive bend-

Fig. 9. Explosion; TEST 2.

ing along the height. The vertical cracks at the corner are results of negative bending moments along the length.

One of the reasons of severe cracking of wall C can be the extreme air pressure that might have developed as a result of explosion in hole-2. While connecting 5 tubes for a 5kg explosion in this hole, one of the explosive tubes inadvertently came very close to the surface. The explosion also threw sizable mass of the earth out of this hole.

Wall B was almost completely intact. However wall D which was parallel to well B suffered some

Fig. 8. Explosion design; TEST 2.

(a): X-axis record for model base and top

(b): Y-axis record for model top only

Fig. 10. Acceleration time histories for TEST 2.
Table 2: Peak Ground and Response Acceleration along X and Y axes; Test 2

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<td>Peak Ground Acceleration along Y-axis</td>
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<tr>
<td>Peak Response Acceleration along Y-axis (model top)</td>
<td>0.6g</td>
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*PGA along Y-axis for test 2 could not be recorded

cracks due to stress concentrations around openings, Fig 11 (d).

Side soil separated from the walls in all cases.

7. Explosion Test 3

(i) Explosion design: The explosion design for test 3 is shown in Fig 12. The holes were fired from hole 1 to 2 to 3 with 750 and 250 milliseconds delays to increase the duration of shaking. The direction of excitation was also changed this time by making Y axis (the shorter wall) as the major direction of excitation. Fig 13 shows explosion activity during test 3.

(ii) Sensor’s positions: Only four sensors, one each at the base and top of walls A and D, were installed to avoid loss of sensors in case of collapse of model.

(iii) Accelerometers record: The ground and model top acceleration time histories along X and Y axes are presented in Figs 14 (a) and (b). The peaks in both the figs clearly indicate the firing of the holes with 750 and 250 milliseconds delays.

Peak Ground and Response Accelerations along X and Y axes for test 3 are given in Table 3.

It can be noticed from table 3 that there is no amplification of acceleration along X axis, instead there is a de-amplification. The most probable reason is that the roof slab separated from shorter walls during test 2 and since the sensor had been installed on the portion of the slab resting on wall A, the slab lagged behind the walls during vibration along the longer walls (X axis) and thus rendered lesser acceleration values than the base.

Fig. 11. Damage to the model as a result of EXPLOSIONS TEST 2.

(a) Typical shear crack in Wall A
(b) Wall B undamaged
(c) Typical shear and flexure crack in Wall C
(d) Sliding of lintel and shear cracks in spandrel

Fig. 12. Explosion design; TEST 3.

Fig. 13. Explosion activity during TEST 3.
(iv) Effects on model: The model experienced heavy damages as a result of explosion test 3, but it never remained standing. The cracks already existing as a result of test 2 widened further. Walls A and C separated from the roof slab in a sliding shear mode as shown in Figs 15 (a) and (c). Wall D suffered severe shear cracks in the spandrel below window. The lintel slid further up to about 1.5 inch tearing also part of wall C. Wall C already cracked as a result of test 2, experienced additional cracks and as a whole got seriously damaged.

CONCLUSIONS
- The technique of firing an array of line charges at suitable time intervals, with the help of igni-

Table 3: Peak Ground and Response Acceleration along X and Y axes; Test 3

<table>
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<tr>
<td>Peak Response Acceleration along X-axis (model top)</td>
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<tr>
<td>Peak Ground Acceleration along Y-axis</td>
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<tr>
<td>Peak Response Acceleration along Y-axis (model top)</td>
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<tr>
<td>Amplification factor</td>
<td>1.3</td>
</tr>
</tbody>
</table>

- The distance between the charge and the model, depth of charge and quantity of explosive shall be worked out based on a preliminary testing program prior to actual test. A distance of 30 ft and depth of 20 ft should render acceptable estimate for first trial. The quantity of the charge will depend on the nature of explosive material used. Generally three to four trial tests will provide sufficient data to design explosion schemes.

Future Recommendations
- In absence of the real earthquake records, controlled explosion testing using arrays of line sources with suitable delay schemes may be employed to produce ground shaking records corresponding to various soil conditions. Such data can be used for development of expert system for generation of artificial ground motion records. The records thus obtained can be used as seismic excitation input for dynamic and soil-structure interaction studies of the numerical models.

Fig. 15. Damage to the model as a result of EXPLOSION TEST 3.
ACKNOWLEDGEMENTS

The investigation described in this paper is part of PhD research work of Dr. Qaisar Ali carried out under the supervision of Prof. Dr. Akhtar Naeem Khan in the Department of Civil Engineering, NWFP University of Engineering and Technology, Peshawar. The authors greatly acknowledge the financial support received from Higher Education Commission Islamabad, Pakistan through its Merit Scholarship Scheme for PhD studies in Science and Technology.

REFERENCES

