13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 3429

A NEW 3-D EARTHQUAKE SIMULATOR FOR TRAINING AND RESEARCH PURPOSES

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SUMMARY

A new 3-D earthquake simulator with a vibrating platform approximately 7 by 4 meters, has recently been put into trial operation in Ankara, Turkey. Motions up to an intensity VIII+ in the MM Scale can be simulated, basing on either "actually recorded" or "synthesized" 3-D digital strong-motion data. Light, sound, smoke and projected video image effects accompany and highly dramatize the vibratory motions. A selection of such motions and effects, together with green/red lights and pre-recorded announcements, can be combined in a variety of ways, in proper order, timing and content, to create a multitude of earthquake scenarios. The simulator is housed in an independent building, specially constructed and equipped. Accomplishment of this comprehensive job required intensive work in a number of specialty areas. Each has been fulfilled by selected companies. The author has carried out the overall and the detailed design, then supervised the activities of r.c. and steel construction, manufacturing, assembling, erecting mock-up decoration and developing specific control software, in addition to product selection and testing [1], [2].

INTRODUCTION

The simulator is jointly owned by the Civil Defense College [3] and Ankara Search & Rescue Unit [4], both connected to the Ministry of the Interior, through the General Directorate of Civil Defense [5]. The main purpose of having such a simulator is to train search & rescue personnel, but it is also intended to keep it open to visits of students, voluntary organizations and the general public [6]. Due to the precision of the motion generation mechanism, it can also be used in educational activities and for scientific experiments on people, on models of soils, structures and equipment.

THE SIMULATOR BUILDING AND ITS EQUIPMENT

Simulation activity takes place in a covered space, provided by a monolithic reinforced concrete shear-wall structure, built in a mini-theater fashion, equipped with professional quality "surround-stereo audio" and "stage lighting" systems, supplemented by a pair of "strobes" and "smoke generators". The plan dimensions are 11 meters by 22 meters (Fig. 1). The number of observer seats has been limited to 130, not to lose the training-hall character (Fig. 2). The "motorized large-size screen" and two "video projectors" can be used either for contributing to vibratory demonstrations or for independent use. Activities can be monitored and/ or documented by means of the "dome camera". All these elements are remote-controlled and can, in turn, be computer-controlled. There exists a foyer downstairs for refreshment service and rest rooms.

Fig. 1 - The Earthquake Simulator Building.

THE VIBRATING PLATFORM ASSEMBLY

The vibrating platform assembly consists of three layers of rectangular steel construction with different sizes and configuration, interconnected by linear sliding mechanisms. Each of the upper two can perform independent horizontal movements along perpendicular (i.e. y and x) axes, respectively, on the one below. The lowermost layer is so guided that it can move only along the vertical (i.e. z) axis. Among these three, only the uppermost layer, actually its top-surface, can be seen by the observers (as surrounded by the dark-blue contour in Figs. 2, 4 and 5). With an area of 6.90 meters by 3.90 meters, it constitutes the “mobile stage” of the mini-theater and displays the resultant 3-D motion (along x, y and z axes) during operation. It is locked otherwise. A combination of portable wall panels, mimicking the view of a vertical cross-section of a building interior, through a kitchen and a living room (Figs. 2 and 4) is fixed onto this uppermost layer. The latter also supports the floor plates, on which tables, chairs and arm-chairs freely stand. The kitchen-boards are fixed onto the walls. The wall panels can be disassembled and removed completely.

ACTUATION MECHANISMS AND DYNAMIC PERFORMANCE

Each layer of the platform assembly is actuated by its own independent ultra-high-power servomotor. Each servomotor is driven by its respective control-amplifier that, in turn, is fed from 380 V three-phase electric lines and controlled by a common PC, dedicated to 3-D motion management. No hydraulics are involved. At present, this Earthquake Simulator is supposed to be the largest in the world, with direct mechanical servomotor actuation.

The rotary motions of servomotors are converted to that of linear, by means of ball-screws. In addition to the weight of its own and of the mock-up decoration, the stage can perform the movements specified below, while carrying a payload of 2,000 kgf. Looking from the observer seats (Fig. 2), the left-right (along x-axis) stroke is 54, the backward-forward (along y-axis) stroke is 50, and the downword-upward stroke (along z-axis) is 18 centimeters. Horizontal velocities up to 80 centimeters per second and vertical velocities up to 35 centimeters per second could be achieved. In terms of acceleration, the limits are over 0.7 g horizontally (along x & y-axes) and over 0.3 g vertically (along z-axis). With the mentioned loads (masses), motions of intensities up to VIII+ in the Modified Mercalli Scale could be achieved. Discernible lateral displacement amplitudes could be achieved up to a frequency of 12 Hz.

Fig. 2 –   The “mobile stage” (surrounded by the blue contour) and the mock-up decoration (cross-section from kitchen and living room), as viewed from a back observer seat. Note front speakers of the audio system and the stage lighting.

AUTOMATED SCENARIO OPERATION

A scenario has a certain 3-D motion in its core, either really recorded or synthesized, and consists of a series of pre-recorded announcements, light and sound effects, supplemented by smoke generation, moving picture video projections and specific controls (green/red warning lights, screen rolling etc.) arranged in an orderly sequence. There is almost no limit to the number of scenarios that can be so tailored and stored. New ones can still be produced as strong earthquakes are recorded or new requirements arise. It is a matter of imagination and creativity. All these elements are controlled by a total of three computers, coupled in a certain fashion, each being dedicated to specific functions (i.e. “3-D motion control”, “multimedia control”, and “the master controls”, respectively). What makes them perform in harmony is the “scenario software”, operating on the master PC. The simulation process can be fully or partly automated by selecting and putting a scenario program into action (Fig. 5), or it can be manually administered issuing step-by-step commands.

In each mode the operation can be effected by pressing on the appropriate part of the menu, appearing on the screen of a hand-held wireless "touch panel". The instructor can walk in the building or sit in one of the seats, holding this panel. He or she can even use it while talking or making explanations.

ARRANGEMENTS FOR SAFETY

The observer side of the "mobile stage" is bound by an inox frame fence (Fig. 5), in order to prevent a case of accidentally throwing out a person during operation, without blocking the view. Thus, all the entries and exits should be through the stage door (seen on the right side of Fig.2). Warning lights, turning red or green as appropriate, are provided for calling proper attention. Soft and hard limit-switches and mechanical bumpers are provided in succession, in order to prevent excessive platform displacements. Pressing on one of the big-red emergency-stop buttons immediately stops mechanical movement.

DISCUSSION AND CONCLUSION

The Earthquake Simulator has been put into trial service only very recently. It proved to be a useful asset, with its neighboring mock-up wrecked 4-story reinforced-concrete building and the climbing tower, within the joint training campus of the Civil Defense College [3] and Ankara Search & Rescue Unit [4] of the General Directorate of Civil Defense [5]. Its capacity further exceeds the one the author had designed in 1995 [7] having a size of 3.60 by 2.50 meters, with unidirectional movement. The large size of the "mobile stage" here permits the accomodation of a range of full-size mock-up decorations for realistic impressions (Fig. 3).

Fig. 3- The full-size mock-up kitchen decoration.

Fig. 4- The mock-up kitchen and living room decoration, with the walls fixed onto the “mobile stage”.

Fig. 5- The “mobile stage” in motion. Note the person lying on the stage-floor on the left for protection, the tilted bookshelves (to be brought back to the upright position automatically, after the scenario ended), the fallen flower-pot near the center, the generated smoke and the moving video image (seen through the window) on the right.

New decorations such as a “classroom”, a “hospital room” and a “factory hall corner” are under consideration. Although it is mainly intended for training search & rescue personnel, there is a great demand from schools, governmental and voluntary organizations, and from the general public. The General Directorate of Civil Defense [5], responds positively and intends to open this facility also to the public [6], to provide general information on earthquakes and training on the survival technics.

The following can be said from this limited-time experience of shaking people:

- The motions are perceived more fully in their violence, by the persons who are actually standing or sitting on the platform. On the other hand, the observers tend to take it comparatively easy, however close their seats are to the platform. This may come partly from the distance effect but mainly from the fact that the observers rest in a mechanically stationary environment, which is further isolated by several mental factors. It can be summarized as: “the severity of the motion is more properly appreciated by persons who actually take place in the mobile environment”. Because of the above mentioned reasons, probably there should not be more than 8 rows of seats (Fig. 2). However, this contradicts with the approach of those, who intend to use this space as a conference hall in other times, once major investments have been made. Then a trade-off follows.

  It has also been noted that, were a “first-hand experimenter” and a “beholder” acquainted in some way (as in the case of classmates), the level of influence on the latter is higher compared to that of otherwise. This suggests to form both groups from the same educational, working or social environment. It will further strengthten the instantaneous and subsequent interaction of experiences.

- Generally the people and the media have distorted opinions about the character, extent and duration of earthquake motions. In the movies it is not uncommon to watch unrealistically large-amplitude motions, lasting minutes. The simulator offers excellent opportunities to adjust the internal scale of people to realistic rates.

- Although the motions are precise mechanical reproductions of actual 3-D strong-motion records, people generally tend to find them weaker than their expectations. They express their surprise as to “how such a great number of buildings have collapsed due to such a tame motion !”. However, this feeling comes from the “assured sense of security” stemming from the walls’ and the decorations’ strength in this public training environment. Another important factor is the “well-known starting time of the event” as necessarily declared by the announcements. Similarly, people can endure very violent motions and collisions in amusement parks, without excessive fears or complaints, but with a taste of excitement. No doubt, much weaker motions starting at an unexpected time, even causing a slight swinging of the ceiling lamp, will be enough to cause alarm and panic in real building interiors. Similarly, a person, at rest or concentrated on a specific aspect (e.g. reading) within a car in motion, is more awkward and apt to panic upon a sudden jolt, than a person carefully watching the road, having the chance to brace himself in advance. It can be concluded that “the fear does not stem directly from the motion itself but from its consequences, and is strongly related to the level of alertness and judged sense of security”.

- If the main purpose is to familiarize persons to violent motions and letting them develop certain reflexes, synthesized motions of unusual extent can be employed. Development of “demonstration motions”, as explained below, stemmed mainly from this requirement. Lighting, audio and smoke effects and projected video images proved to further dramatize the influence of shaking. However, the persons should be told about the fact that the conditions are exaggerated, not to distort their internal scales. They should also be given the opportunity of comparing it with the realistic ones.

- Turkey is an earthquake country and similar facilities should be established in major sites of settlement, for training purposes. For an ordinary person living in a certain locality, it is very likely to experience a number of minor tremors and at least one moderate-intensity earthquake, within his lifetime. Although it may kill thousands of people when it happens, an encounter with a really intensive one is quite rare, considering the whole population in the statistical sense. This also holds true for search & rescue personnel, who routinely experience aftershocks. On the other hand, the Simulator offers training at unusually high intensities without posing any danger. After several years of continued operation, the percentage of the population acquainted with survival technics, having developed seismic-consciousness and internal scale for proper perception of the pertinent risk, may reach a considerable level.

The author has already started the following applications on the simulator, for providing better visualization and insight in the general field of "Engineering Seismolgy" on one hand, and for experimentally supporting his lectures in the Department of Geophysical Engineering [8] of Ankara University [9], on the other:

- Derivation of a series of "demonstration motions" from "actual" or "synthesized" data, and then categorizing them in half-degree steps between V and VIII+ in the Modified Mercalli Scale, depending solely on human response, with the purpose of interpreting the correlation of intensities with maximum velocities and accelerations, experimentally. This process can be repeated at different times, with different people, and perhaps with different ways of interpretation. Up to now, numerous excellent attempts have been made to reach such correlations, depending on evaluations made during past "one-time-lived" earthquakes, e.g [10] and [11], just to mention a few. Due consideration is being given to these references as they also base on building damage information.

- Demonstration of the attenuation of ground-motion with distance, employing "actually recorded" motions.

- Demonstration and comparison of vibration amplitudes of the ground and the upper floors of multistory buildings, employing "actually recorded" motions.

- Demonstration of modification and possible amplification of the base-rock motion by an intermediate soft soil layer, employing "actually recorded" and/or "computed" motions.

- Demonstration and comparison of vibration mode shapes and periods of multi-degree-of-freedom systems, on "representative physical models", employing "synthesized sinusoidal" motions.

- Demonstration of earthquake response of various building types (e.g. masonry, framed etc.), on "representative physical models".

- Demonstration of effects of base-isolation, on "representative physical models".

- Demonstration of effects of energy-absorbing devices employed in the superstructure, on "representative physical models".

- Demonstration of the effects of tuned-mass dampers, on "representative physical models".

- Demonstration of the destruction process in masonry buildings, on "representative physical models".

- Demonstration of the destruction process in framed buildings of ductile and fragile materials, on "representative physical models".

ACKNOWLEDGEMENT

The author thanks for the kind permission given him by the Civil Defense College and Ankara Search & Rescue Unit, General Directorate of Civil Defense, Ministry of the Interior, Government of Turkey, to submit information on their Earthquake Simulator. The making up of this prototype, necessarily going through numerous experimental steps and repetitions, could not have been possible without the dedicated and voluntary work of a number of persons and private companies, at times assuming the character of technical wrestling, leaving routine commercial worries aside. The author, as the principal designer and the delegated supervisor, highly appreciates their cooperation, patience and shared motivation.

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