A Major Project on

ESTABLISHMENT OF EARTHQUAKE ENGINEERING LABORATORY

Submitted in Partial Fulfilment for the Award of the Degree of

MASTERS OF TECHNOLOGY

IN

CIVIL ENGINEERING

(STRUCTURAL ENGINEERING)

By

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July-2012

DELHI TECHNOLOGICAL UNIVERSITY

CERTIFICATE

This is to certify that the project report entitled "ESTABLISHMENT OF EARTHQUAKE ENGINEERING LABORATORY" is a bonafide record of work carried out by me under the guidance and supervision of **Mr. Alok Verma** (Associate Professor), during the session 2012 in partial fulfilment of the requirement for the degree of Master of Technology (Structural Engineering) from Delhi Technological University, Delhi.

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ABSTRACT

Although considering the dynamic behavior of buildings and bridges is of fundamental importance in modern structural design, undergraduate civil engineering students seldom develop an understanding of the way that these structures respond when acted upon by time-varying loads. Because this topic is of great social and economical importance, there is a need in current civil engineering programs to provide more formal training in structural dynamics and earthquake hazard mitigation at the undergraduate level. Further, many students in non-engineering disciplines would gain from such exposure to basic concepts in earthquake engineering.

This paper traces the establishment and development of earthquake engineering in any Engineering Institution for focusing primarily on improving and developing the knowledge as well as research prospects in the field of earthquake engineering. The development of earthquake engineering laboratory is studied in the topmost Indian Institute of Technology viz. I.I.T. Roorkee and I.I.T. Kanpur, along with more specific detail on the development of innovative design principles and solutions, such as the employment of capacity design principles, the formulation of engineering-based design standards for house structures, and the development of base isolation systems for structures.

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INTRODUCTION

CHAPTER 1

INTRODUCTION

One of the most important challenges facing structural engineers of today is the development and implementation of effective techniques for minimizing the severe and often tragic consequences of earthquakes. To meet this challenge, future structural engineers must possess an understanding of the dynamic response of structures such as buildings, bridges, and towers to strong ground motion. Although considering the dynamic behavior of these structures is of fundamental importance in modern structural design worldwide, undergraduate civil engineering students seldom develop an understanding of the way that these structures respond when acted upon by time-varying loads. There is a need for integrating this important topic into the undergraduate curriculum.

Experiments are quite effective for demonstrating basic concepts in structural dynamics and earthquake engineering. Even at the undergraduate level, concepts in dynamics such as natural frequencies and mode shapes can clearly be portrayed during such experiments. To gain an understanding of the behavior of structures subjected to earthquakes, it is helpful to have the capabilities of modifying the dynamic characteristics of the test specimens, selecting different earthquake inputs, and measuring and analyzing structural responses. Students could learn these principles through the introduction of a series of “hands-on” experiments and classroom demonstrations throughout their coursework.

Earthquake simulator tables, or shake tables, are traditionally used for experimental research in earthquake engineering. These instruments are capable of reproducing the motion of the ground during an earthquake, allowing for controlled testing of structures subjected to earthquakes. New concepts and techniques are often tested on scaled structures using shake tables before implementation on actual structures. Shake tables have been used at several universities for educating students about earthquake engineering and structural dynamics. However, few universities have shake tables and due to testing schedules only a handful of these universities have the freedom to provide students with access to these instruments. Moreover, “hands-on” experiments are not feasible due to the size of the equipment and the specialized training required to operate such systems safely.

Bench-scale shake tables are an ideal alternative to provide students access to such “hands-on” experiments. At this scale, students can observe earthquake responses, design and build model structures, modify their structures, measure structural responses, and reproduce several earthquake records. Further, bench-scale tables are mobile enough to bring into the classroom or even to local grade schools for demonstrations. Thus, it is desirable to introduce experiments based-on the use of bench-scale shake tables into the undergraduate curriculum.

The focus of this study is to provide a detailed description of the necessary machines and instruments that are necessary to perform the experiments in earthquake engineering laboratory.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Some of the largest earthquakes of the world have occurred in India and the earthquake engineering developments in the country started rather early. After the 1897 Assam earthquake, a new earthquake resistant type of housing was developed which is still prevalent in the north-east India.

The institutional development started in the late 1950's and earthquake engineering concepts have been applied to numerous major projects in high seismic regions in the country.

Extensive damage during several moderate earthquakes in recent years indicate that despite such early gains, earthquake risk in the country has been increasing alarmingly. Most buildings even in high seismic regions of the country continue to be built without appropriate earthquake resistant features. At the higher end of earthquake technology, the gap between state-of-thepractice of earthquake engineering and research in India, bench-marked against the advanced countries, has been widening.

On the one hand, the country has failed miserably in ensuring earthquake-resistant constructions in high seismic regions. On the other hand, numerous major projects such as large dams and nuclear power plants have been built in high seismic regions with due regard to earthquake safety and for which seismic analysis and design have been handled within the country. Also, considerable experience has been gained in the country in seismic repair and strengthening of masonry buildings following a number of moderate earthquakes in the recent years. Yet, at the higher end of the earthquake technology, the gap in our state-of-the practice with the developed countries has been widening. Till date, no structure in India has utilised base isolation or other seismic control devices; the only exception is the construction in progress of two base-isolated one-storey demonstration buildings in Killari village in the 1993 Latur earthquake affected region (EERI, 1999).

2.2 INSTITUTIONAL DEVELOPMENT

The establishment of a separate Department at Roorkee proved instrumental in rapid early growth of earthquake engineering in India. The DEQ provides under one roof all disciplines associated with earthquake engineering and currently has about 25 faculty members. It was developed unlike other typical academic departments in the sense that providing consultancy and testing services was one of its major aims and this enabled the incorporation of earthquake engineering inputs into major projects. However, the presence of such a department also had a somewhat negative fall-out as it was felt that the DEQ can provide whatever earthquake solutions the country needs, and no efforts were made towards further institutional development. For instance, the five prestigious Indian Institutes of Technology

(IIT's) and concerned laboratories of the Council of Scientific and Industrial Research (CSIR) did not take up earthquake engineering in a significant manner until very recently. This meant that the number of highly-trained manpower got highly restricted. More importantly, the DEQ was in a peculiar situation of having to meet two often conflicting objectives: on one hand to promote earthquake engineering education and carry out research and development, and on the other hand, carry out enough industrial consultancy to meet bulk of its expenditures. This also blurred the difference between the Department encouraging and supporting the professional engineers versus it competing with the professional firms. And finally, it did not challenge the Department to have a healthy competition from groups in other institutions.

Undergraduate civil engineering education in India, as in other countries, does not expose the students to the issues of seismic risk. In the post-graduate programmes in structural engineering, some students may get exposed to dynamic analysis and a still fewer numbers to aseismic design (Murty et al., 1998). The total number of Master's graduate from DEQ, IIT's and other premier institutions with specialisation in earthquake engineering will perhaps be less than 40 per year and many of them choose a non-civil engineering career. Thus, a huge engineering work force, having no formal exposure to seismic design in college, requires training through continuing education programmes. Short courses for professionals have been conducted at Roorkee for a long time now.

Since 1992, IIT Kanpur has conducted numerous short courses on seismic design of reinforced concrete buildings, the most common type of multi-storey buildings in urban areas.

2.3 RESEARCH FACILITIES

A 3.5m x 3.5m biaxial shake table was installed at Roorkee in 1986 with a 20 tonne payload capacity. This is the only large shake table available in the country for earthquake engineering work, and hence, has been used primarily for testing rather than research. Clearly, more such facilities are needed; moreover, even this facility now needs major upgradation. Modest facilities for conducting cyclic tests on structural components using state-of-the-art actuators are now available at several of the Institutions: IIT's at Kanpur, Bombay, Delhi and Madras, Roorkee University and some of the CSIR laboratories. The country is yet to develop or acquire a large eccentric mass shaker for carrying out forced vibration tests on proto-type structures.

2.4 EDUCATION AND TRAINING DEVELOPMENT

In a developing country such as India, basic poverty issues like food, shelter, health, and education remain the highest priority and natural disaster mitigation does not get the priority that it should. Amongst the major challenges ahead is to sensitise the policy makers, the politicians and the administrators to the issues of earthquake safety. With five damaging earthquakes in the last eleven years, this is the right time to initiate a sustained and proactive effort in this direction.

2.5 OBJECTIVE AND SCOPE OF PRESENT INVESTIGATION

In this project, a study of the earthquake engineering laboratory at Indian Institute of Technology, Roorkee and Indian Institute of Technology, Kanpur is presented. Both the instruments which are necessary and which are essential for the earthquake laboratory are studied with their specifications as per the requirements. Then a comparable study is done in order to buy the equipments from the manufacturers as per the needs of the laboratory so that the overall project in establishing the earthquake laboratory is made economical according to the type and level of the engineering institution.

CHAPTER 3

A STUDY ON EARTHQUAKE ENGINEERING LABORATORY

INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE

CHAPTER 3

A STUDY ON EARTHQUAKE ENGINEERING LABORATORY

INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE

3.1 About the department:

The Department of Earthquake Engineering at the Indian Institute of Technology Roorkee (erstwhile University of Roorkee) was established in 1960 as ‘School of Research and Training in Earthquake Engineering’ and was renamed as Department of Earthquake Engineering in 1978.

Four major areas of Earthquake Engineering viz. Structural Dynamics, Soil Dynamics, Engineering Seismology and Seismotectonics, and Instrumentation have been nurtured for the last fifty years.

The major functions of the Department include teaching and research, and rendering expert advice to various organisations in the area of earthquake resistant design of structures and systems, such as dams, bridges, power plants, etc.

Several major facilities have been developed in the Department to conduct experiments related to Earthquake Engineering. Some of the major facilities include: a low cost railway wagon shock table for dynamic testing of structural models, a computer controlled shake table to simulate strong ground motion, a quasi static testing laboratory having servo-controlled dynamic actuator systems and serve-controlled compression testing machine, a soil dynamics laboratory equipped with liquefaction table and cyclic triaxial testing system, a seismological observatory having sophisticate digital broadband seismograph to record earthquake ground motion, a strong motion network of 300 digitals accelerographs developed in Himalayan region to measure strong ground motion due to moderate and major earthquakes and a state-of-the-art 12-stations telemetered network to monitor to monitor local seismicity in the environs of the Tehri dam.

3.2 Field of Specializations:

3.2.1 Structural Dynamics

3.2.3 Soil Dynamics

3.2.3 Engineering Seismology and Seismotectonics

3.2.4 Instrumentation

3.3 Major Facilities:

3.3.1 Computer controlled Shake Table

3.3.2 Shock table for full scale testing

3.3.3 Structural dynamics laboratory

3.3.4 Quasi static testing laboratory

3.3.5 Soil dynamics laboratory

- Dynamic tri-axial testing
- Liquefaction testing facility

3.3.6 Seismological observatory

- Strong motion network of 300 digital accelerographs
- 12-stations telemetered network in environ of Tehri dam

3.3.1. Shake Table (computer controlled)

It is the unique national facility for testing of equipment and structures under earthquake excitation. The development has reached to a stage where earthquake simulation is achieved in laboratory. Shake table is used for the seismic qualification studies in providing earthquake simulation and to test the prototype and scaled model of the structure.

Shake table facility was created by the Department of Earthquake Engineering, Indian Institute of Technology, Roorkee (the then University of Roorkee) in the year 1986 through funding from UGC under SAP and COSIST schemes. The table motion can be either an earlier recorded real earthquake or an artificial earthquake motion compatible with a given response spectra.

Fig.3.1: Model of Shaking Platform

Fig.3.2: Side view of Model of Shaking Platform

Fig.3.3: Shake Table in the Laboratory

Fig.3.4: View of the Shake Table

This facility has been upgraded recently with the financial assistance from Department of Science and Technology, Government of India.

Specifications:

- Size : 3500 mm X 3500 mm
- Capacity : 20 tonnes
- Motion : One horizontal and vertical simultaneously
- Actuators : One horizontal and two vertical
- Earthquake Excitation : Time history matching, Response spectra matching
- Other Excitation : Sine wave, Sine sweep
- Data Acquisition : 128 Voltage Channels (64 Channels without implification and rest with amplification)

S.No.	Characteristics (Units)	Horizontal Actuator	Vertical Actuator
1.	Static Thrust (kN)	250	125
2.	Dynamic Thrust (kN)	200	100
3.	Stroke (mm)	300	300
4.	Velocity (mm/sec)	1200	1500
5.	Oil flow at maximum velocity (L/min)	750	400

Table 3.1: Characteristics of Shake Table

Many critical equipment needs to be tested for their performance under seismic environment and shake table studies are required by many standards such as IEEE-693, Bellcore-GR-63, etc. At IIT Roorkee shake table many such tests were conducted for nuclear and other industrial applications.

Fig.3.5: Gantry Crane in Shake Table Lab

Fig.3.6: View of the Shake Table Laboratory

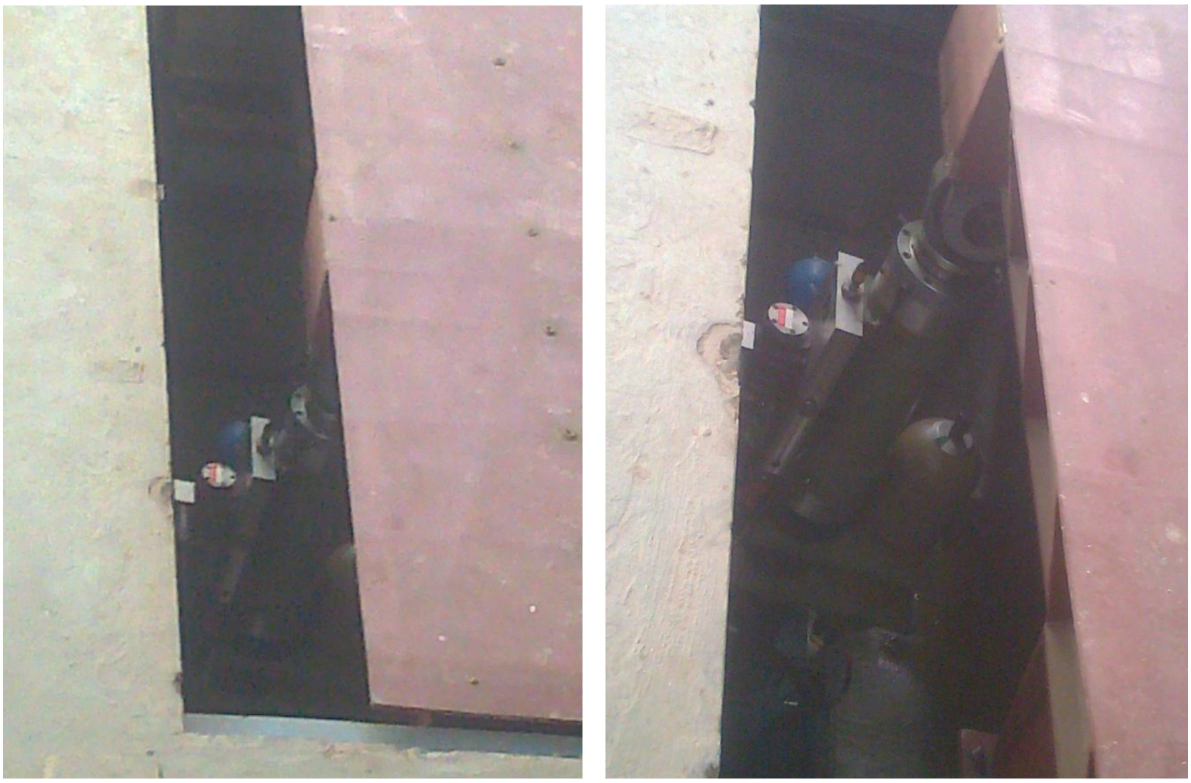

Fig.3.7: Actuators for the vertical excitement of the Shake table

Fig.3.8: Lateral support to the Shake table to avoid the lateral movement

3.3.2. Shock Table (for full scale testing)

It is equipped with a railway track and wagon system. It is used for the dynamic testing of structural models. The model is erected on the rigid steel platform having railway axel-wheels which can role on the rail track. On the either side of the platform, there are two heavy load trolleys filled with stones which roles down on the inclined track and hit the rigid platform in between giving the platform an instant shock and a dynamic force to the model.

Fig.3.9: Shock Table and Loaded Wagon on the elevated railway track

Fig.3.10: Test specimens

Fig.3.11: Loaded wagon hitting the Shock table platform

The shock table is used to perform the following:

1. Full scale testing of equipment
2. Installation of strong motion instruments
3. Laboratory testing of soils
4. Model testing of structures
5. Micro-earthquake field surveys
6. Seismological instrumentation

In the model testing of structures, test conducted between normal masonry building and earthquake resistant building, normal masonry building get collapsed due to the lateral dynamic forces generated by a shock. As can be seen in the figure, earthquake resistant building overcomes the dynamic forces rendering the building safe.

Fig.3.12: Behaviour of the normal reinforced building and earthquake resistant brick masonry building due to lateral shock

Fig.3.13: Performance of earthquake resistant brick masonry building due to shock

Fig.3.14: Earthquake resistant stone masonry building showing earthquake resistant building requirement

3.3.3. Structural Dynamics Laboratory

The laboratory was established to conduct research activities and to support teaching in courses related either directly or indirectly to the main working areas. This laboratory is aimed at complementing and augmenting the basic need for designing the structures for dynamic (or time varying) loads. While the primary emphasis is on the design for earthquake effects. It is equipped to handle any dynamic problem, such as strong winds, machine induces vibrations, etc.

The Structural Dynamics Laboratory includes facilities for performing vibration and modal testing. This equipment includes laser vibrometers, accelerometers, electrodynamic shakers, computers and data acquisition systems.

3.3.4. Quasi-static Testing Laboratory

Computer controlled servo-hydraulic multi-actuator testing systems allow for fatigue testing, quasi static testing including Pseudo-Dynamic Testing (PST). In PST a large scale test structure is attached to a strong floor, strong wall, and/or reaction frame and excited slowly at low frequencies with multiple actuators. A PC-based digital controller measures and controls the force and displacement of each actuator. Fatigue and basic quasi static testing use open loop control to drive the actuators with a pre-programmed time history or block cycle.

Components of a typical quasi static testing system include:

a) Structures laboratory with strong floor and walls with attachment inserts.
b) Multiple actuators with static force rating of 100 kN -1000 kN. Stroke from +/- 100 mm to +/- 400 mm. Peak velocity of 1 cm/s -10 cm/s.
c) Hydraulic power supplies rated for fatigue operation and 15-180 GPM.
d) Hydraulic power supply with capacity of 30-300 GPM (110-1100 L/min) at 3000 psi (21 MPa).
e) Hydraulic hoses to place the actuators up to 30 m from the strong wall or strong floor local manifolds (with quick release connectors).
f) 5-15 GPM two-stage servo valves (option for larger valves).
g) Frequency response 0-20 Hz.
h) Additional strain or displacement measurement transducers, as required.

S.No.	NAME OF THE INSTRUMENT	MANUFACTURER
I.	Compression Testing Machine (Servo-controlled)	CONTROLS
II.	Flexure Testing Machine	CONTROLS
III.	Reaction Wall (for lateral load)	
IV.	Actuators (displacement based)	INSTRON

Table 3.2: Name of the Instrument and its Manufacturer

3.3.4.1 Compression Testing Machine (With Cyclic option):

a) Compression Testing Machine is equipped with Strain Gauge, LVDT and Extensometer.
b) It is a CTM-4P-300 Compression Testing Machine Digital type.
c) 2000KN (200 Tons)/ 3000 KN (300 Tons) Capacity (Two Pillar Model)
d) Electrically operated
e) Fitted with Digital Load Indicator with accuracy of 1KN.
f) The digital load indicator incorporates peak hold facility and relay contact to protect the machine from overloading.
g) The Machine is suitable for operation on 440V, 3-phase, AC supply.
h) The machine is calibrated against a NPL/NCCBM certified proving ring.

Fig.3.15: CTM-4P-300 Compression Testing Machine Digital type

3.3.4.2 Flexure Testing Machine : (53-C0004 and 53-C0005 series)

These machines are designed to conform to the essential requirements of IS 9399-1979 or on request IS 516. It can test beams of 100 mm and 150 mm square cross sections.

It is ideal for Commercial laboratories, Precast concrete producers and Hollow brick producers for testing Flat blocks (BS 6073-1), Clay blocks for flooring - UNI 9730-3, Hollow tiles UNI 2107, Concrete and clay roof tiles EN 491 and EN 538.

Fig.3.16 (a): Flexure Testing Machine

Fig.3.16 (b): Flexure Testing Machine

Main Features :

- 50 kN max. Capacity
- Large horizontal span: 520 mm
- Infinitely variable test speed: 0.1 to 51 mm/min
- DC motor 1,1 kW (53-C5/A model only)
- Voltage 230 V, 50-60 Hz, 1 ph
- Also available for 110V,60 Hz

3.3.4.3 Reaction Walls :

The quasi static laboratory is equipped with two **Reaction Walls** both next to strong floor. The walls and base of the reaction structures are constructed with prefabricated post-compressed reinforced cement concrete blocks and have the following dimensions.

Fig.3.17: Reaction Wall (North)

- **Reaction Wall (North)**

Length (m)	14.40
Height (m)	12.00
Thickness (m)	02.40

- **Reaction Wall (west)**

Length (m)	09.00
Height (m)	12.00
Thickness (m)	02.40

Table 3.3: Dimensions of North and West Reaction Wall

Fig.3.18: Test specimen

3.3.4.4 Actuators :

A rod, mounted on the load frame that is driven up or down using servo-hydraulic force. The force required to drive the actuator is transferred to the specimen through the grips. Actuator applies to servo-hydraulic systems only. Note that the crosshead is fixed during a test on a servo-hydraulic system.

Main Features :

- 11 high-performance dynamic and static actuators
- Variable force capacity (250 to 2500kN) providing the ability to conduct
    - quasi-static,
    - pseudo-dynamic and
    - hybrid pseudo-dynamic testing.

Fig.3.19 (a): Actuator (displacement based) by INSTRON

Fig.3.19 (b): Actuator (displacement based) by INSTRON

Fig.3.19 (c): Actuator (displacement based) by INSTRON (A Close view)

3.3.5. Soil Dynamics Laboratory

It is equipped with the following instruments:

3.3.5.1. Dynamic Consolidometer

3.3.5.2 Oscillatory Shear Box

3.3.5.3 Vertical Shake Table

3.3.5.4 Liquifaction Table

3.3.5.5 Cyclic Tri-axial Testing System

3.3.5.1. Dynamic Consolidometer:

At a project site where loose to medium dense 'clean' sands were encountered are found to be susceptible to liquefaction to about 8-12 m depth. So Dynamic compaction is carried out across such entire site to densify the soils and mitigate the risk of liquefaction. Field tests (including standard penetration tests and static cone penetration tests) carried out before and after dynamic compaction can also be performed for ground improvement to the desired depth. Open foundations bearing on the improved ground can then be provided in place of piles, resulting in enormous cost-saving for the owner.

Fig.3.20: Dynamic Consolidometer

3.3.5.2. Oscillatory Shear Box:

Dynamic oscillatory shear tests are performed by subjecting a material to a sinusoidal deformation and measuring the resulting mechanical response as a function of time. Oscillatory shear tests can be divided into two regimes. One regime evokes a linear viscoelastic response (small amplitude oscillatory shear, SAOS) and the other regime is defined by a measurable nonlinear material response (large amplitude oscillatory shear, LAOS). As the applied amplitude (of strain or stress) is increased from small to large at a fixed frequency, a transition between the linear and nonlinear regimes can appear.

Fig.3.21: Oscillatory Shear Box

3.3.5.3. Vertical Shake Table:

The vertical shake tables are similar to the horizontal shake table, except for the primarily motion in vertical direction. These are manufactured in accordance to the recommended standards of the industry,institutions,etc.

Fig.3.22 : Vertical Shake Table

Salient features:

- Variable Speed Controller
- Versatile application areas
- Durable

3.3.5.4. Liquifaction Table:

The test bin is a tank 1.05 m long, 0.60 m wide and 0.60 m high, in which soil sample is prepared. The test set up is shown in Fig. 5. The table can produce one-dimensional (horizontal) steady state vibrations.

Fig.3.23: Liquefaction Table at Dept. of Earthquake Engineering, IIT Roorkee

Fig.3.24: Liquefaction Table at Dept. of Earthquake Engineering, IIT Roorkee

3.3.5.5. Cyclic tri-axial Testing System:

It is used to perform Strain controlled tests on cyclic triaxial samples (**Figure 2**) collected from different depths at an axial strain of 0.7% (seismic zone IV) and at a frequency of 1 Hz.

Fig.3.25. Cyclic Triaxial System at the Department of Earthquake Engineering, IIT Roorkee.

For the laboratory tests, the cyclic triaxial system with the following specifications can be used:

Capability: Static, Cyclic, Stress Path
Dynamic Load: up to 5 kN
Dynamic Displacement: 15 mm
Frequency: 0 – 10 Hz

Fig.3.26: Cross bore hole wave propagation test equipment

3.3.6. Seismological Observatory

A seismological observatory have sophisticate digital broadband seismograph to record earthquake ground motion, a strong motion network of 300 digitals accelerographs developed in Himalayan region to measure strong ground motion due to moderate and major earthquakes and a state-of-the-art 12-stations telemetered network to monitor to monitor local seismicity in the environs of the Tehri dam.

Fig.3.27: Way to the Basement of the Seismological Laboratory

Fig.3.28: Basement of the Seismological Laboratory

The observatory is equipped with the following instruments :

(a). A solid Concrete Pit (10-15 feet deep):

It is isolated from the earth to avoid the unnecessary vibrations other than the vibrations generated due to earthquake (Figure:3.29).

Fig.3.29: A solid Concrete Pit (10-15 feet deep shown in yellow color)

(b). Micro earthquake recorder (Manual) (Figure: 3.20).

Fig.3.30: Micro earthquake recorder (Manual)

(c). Sensors :

- 1st sensor – Digital Unit
- 2nd sensor – Analogue Unit (equipped with three internal sensors)

(i). Digitizer:

The lab consists of The Guralp Systems range of digitisers which offer high-quality full 24-bit resolution, designed for data quality and durability. They are available with a range of input ports, memory and communication options.

Fig.3.31: DM24S6EAM – Authenticated 6 channel digitiser with acquisition module

Main Features:

- From 3 to 24 low noise 24-bit ADCs
- Additional full-rate data channel for user signals and calibration
- Low power 32-bit DSP and ARM processor
- Multiple concurrent data rates up to 1000 samples/s
- STA/LTA ratio, level, external and software triggering
- UTC time stamped data from attached GPS receiver
- 8 environmental channels with 20-bit resolution (3 × mass position, temperature, 4 × user)
- Full control of Guralp broadband seismometers
- Calibration using step, sinusoid or pseudo-random broadband noise signals
- Up to 256Gb Flash memory with fast FireWire data transfer (EAM models only)
- Fully configurable using Guralp data modules and software.

(ii). Guralp CMG-40T Intermediate Sensor:

The CMG-40T is an ultra-lightweight seismometer consisting of three sensors in a sealed case, which can measure the north/south, east/west and vertical components of ground motion simultaneously.

Fig.3.32 (a): CMG-40T Intermediate Sensors (Analogue)

Fig.3.32 (b): CMG-40T Intermediate Sensors (Analogue)

The 40T has a rugged, waterproof stainless steel design for ease of installation. The lightweight sensor elements are designed so that no mechanical clamping is required. Because of this, the 40T is ready to record ground movements as soon as you provide it with power.

In addition, the sensor does not have to be levelled or centred as long as the base is within 3 ° of horizontal. For the best results, however, you should install where possible on a hard, near-horizontal surface well coupled to the bedrock. Each seismometer is delivered with a detailed calibration sheet showing its serial number, measured frequency response in both the long period and the short period sections of the seismic spectrum, sensor DC calibration levels, and the transfer function in poles/zeros notation.

Salient Features:

- Flat response to velocity from 30 seconds to 50 Hz
- Low power
- Easy to use - No Mass lock/unlock; Masses are free to move at all times

(d). Data Analysis System (DAS: Digital)

RS-485 based Data Acquisition System describes hardware architecture theoretical concepts, functionality and development of man machine interface of virtual instrument used for monitoring of real world signals interfaced to serial port of PC. In today's field of automation, on line data monitoring is one of the primary and most important task. The technological innovations in computer industry have revolutionized the way measurements are made with full integrity and desired level of accuracy. With the development of various bus standards such as USB, RS485, PCI., RS-232, PCMCIA, PXI, etc and upcoming of various computing platform different types of data acquisition systems have emerged. RS-485 is one of the most important industrial serial balanced transmission line standard to transmit and receive data at speed of 9600 bps or more over long distance of 1.4km.

When large-channel data acquisition is resident on the seismic computer system, a companion data analysis package is available to streamline the examination and reduction of the specimen data. The functions to be developed have not been finalised, but a preliminary list is presented. The software functions fall into three categories:

a). configuration;
b). time series analysis;
c). spectrum analysis.

a).Configuration:

The software provides the ability to configure the data acquisition channels with special names to identify the actual transducers located at the specimen. In this way, the data for single-output transducers such at LVDT's accelerometers, and multiple-output transducers such as rosette gauges can be analysed by using logical and meaningful names. This feature reduces the possibility of error when manipulating large amounts of data.

b).Time Series Analysis:

Several functions are available to operate upon data in the time domain. Some of the functions result in new time histories and others determine key characteristics. They are listed below: Decimation, arithmetic manipulation, digital filtering, differentiation, integration, mean level, extreme value, rms acceleration, total earthquake energy, strain gauge reduction.

c). Spectrum Analysis:

Several functions are available which operate upon data in the time domain and result in various types of frequency spectrums. They are listed below: Forward and inverse Fourier transformation, response spectrum, auto-spectral density, cross-spectral density, ordinary coherence, transfer function.

CHAPTER 4

A STUDY ON CIVIL ENGINEERING LABORATORY

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

CHAPTER 4

A STUDY ON CIVIL ENGINEERING LABORATORY

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

4.1 About the Department

The Department of Civil Engineering at IIT Kanpur is producing since 1961, high quality technical manpower needed by industry, R&D organizations, and academic institutions. The academic activities of the Department emphasizes deep understanding of fundamental principles, development of creative ability to handle the challenges of Civil Engineering, and the analytical ability to solve problems which are interdisciplinary in nature.

Fig.4.1: Psedo Dynamic Laboratory, IIT Kanpur

4.2 Various Ancillary Equipments

4.2.1. Pseudo Dynamic Laboratory
4.2.2 Servo-hydraulic actuators and Eccentric mass shaker
4.2.3. Vibration measurement and PC-based datalogger.

Major equipment:

a. SH actuators (5) & controllers
b. Load handling equipment
c. High-Performance data acquisition & sensors
d. Welding, cutting & drilling machines
e. Specimen sampling and fixing tools

4.2.1. Pseudo Dynamic Laboratory

This facility provides an affordable means for simulation of earthquake loading for prototypical structures as large as full-scale three-storey building or 15m long bridge. This 500 sq. m new lab space is served by 200 kN EOT crane with its ceiling height at 15 m. The integrated strong floor and wall (10x15x4.0 m three cell box girder floor and 10.5 m high, 2 m thick post-tensioned walls) provide a rigid three-axis reaction system for application of vertical and lateral loads. Anchorages on walls at 0.6 m grid are capable of 2 MN for axial load and 1.5 MN for shear loads.

Integrated Reaction Floor-Wall System 10 m x 15 m x 5.0 m box girder floor 10 m wall with 2.5 m thick wall Post-tensioned wall Anchor points at 0.6 m centers.

The laboratory is equipped with:

4.2.1.1 Universal Testing Machine
4.2.1.2 Compression Testing Machine
4.2.1.3 Column Testing Machine
4.2.1.4 Dynamic Loading Machine

In the extension of the structural engineering laboratory to Pseudo-dynamic laboratory was funded by FIST, NPEEE,& IITK and was estimated to 500 lakhs in Indian currency.

4.2.1.1. Universal Testing Machine:

The present UTM works on principle of manual hydraulic control and all the mechanical tests are performed under load control mode only.

Fig.4.2: 2000 kN Universal Testing Machine(Tinious Olsen,USA,)

4.2.1.2. Compression Testing Machine:

Fig.4.3: 1350 kN Compression Testing Machine (RIEHLE Instruments, AEMTEK Inc., Illonois)

4.2.1.3. Column Testing Machine:

Upgraded to include displacement control (in addition to the computer-based control and data acquisition), to give a technological jump over the current force control and manual operation.

Fig.4.4: 6000kN Column Testing machine (WPM,Germany)

4.2.1.4. Dynamic loading machine:

Fig.4.5: Dynamic Loading Machine

Tests performed in the laboratory:

Fig.4.6: Test specimen of prismatic sample of slab

Fig.4.7: Model of a brick masonary wall(half scale model) developed for studying its behavior against horizontal acceleration(seismic behavior)

4.2.2 Uni-axial Servo-hydraulic Shake Table Facility

This facility is in-house designed and assembled for true simulation of earthquake motion for small scale models of structures. The servo-hydraulic driven shake table platform is 1.2x1.8 m which has a pay load capacity of 40 kN and can generate Kobe class earthquake motions with its maximum velocity of 1.5 m/s. The shake table is fixed to in-house built 800 kN reaction block which is in the form of 8x4.5m new floor space suitably isolated from the rest of laboratory structures. It was developed at less than one-third the cost of the fully imported system.

Fig.4.8: Uni-axial servo-hydraulic shake table facility

Various components of the shake table system assemble and work simultaneously to produce the desired motion. The desired displacement time history or acceleration time history is inputted into the controller. The input displacement command is then converted by the controller to voltage time history which controls the spool openings in the servo valve. The spool opening and the pressure difference across it determines the flow of oil which further determines the force which the actuator applies on the shake table to produce the desired displacement. After implementing the command given by controller error is calculated between actual and desired motion. The controller has inbuilt feedback mechanism which it utilizes in correcting the voltage time history in real time. The data acquisition forms another major part of the shake table system. Sensors like peizo-accelerometer, LVDT and SS-1 are generally used to measure shake table's response.

Salient features:

- 50 kN payload & 1.2 x 1.8 m platform
- 800 kN reaction mass – strong floor
- In-house built
- Can simulate Kobe-class motions
- Excellent motion simulation

4.3 Reaction Frames:

Large capacity self-equilibrating test frames for shear loading of research specimen which are designed and fabricated in-house.

Fig.4.9: Reaction Frames, IIT Kanpur

Salient features:

i. Integrated Reaction Floor-Wall System 10 m x 15 m x 5.0 m box girder floor 10 m wall with 2.5 m thick wall Post-tensioned wall Anchor points at 0.6 m centers.

ii. Double box type of structural testing floor of size 20m x 8.5m designed to carry reversal of loads (180 kN in tension/compression) at every 0.5m spacing in both the directions.

iii. Reaction frames for 250 kN vertical loads and 2000 kN lateral load and 6000 kNm moment.

CHAPTER 5

EARTHQUAKE ENGINEERING LABORATORY

MACHINES AND INSTRUMENTS

(SPECIFICATIONS AND COMPARISION)

CHAPTER 5

MACHINES AND INSTRUMENTS

(SPECIFICATIONS AND COMPARISION)

5.1 Universal Testing Machine

Technical Specifications:

Manufacturer -->	**ETS Intarlaken Technologies**	**BANBROS Engg.Pvt.Ltd.**	**Scientific International**
Capacity	5-300 ton	50kN	40 ton/ 400 kN
Min. Resolution	1/10000	1/20000	
Accuracy	±1	±1	±1
Driving Method	Hydraulic System	Floor Type Machine	
Ram Stroke (mm)	100-250		200
Column Interval (mm)	300-750		500
Speed (mm/min)	50-250		
Machine weight approx. (kg)	1500-4000	700	1600
Power	220/440 V, 50Hz	1.5 kw	2.5 HP
Tension clearance (mm)	700	600	50-700
Compression clearance (mm)	700	575	0-700
Dimension (mm)		945x654x2176	2032X600X1960

Table 5.1: Universal Testing Machine Specifications available in the market

5.2 Compression Testing Machine: (by CONTROL'S)

Fig.5.1: 50-C5632 3000kN Compression Machine

Technical specifications:

Models	**50-C4632 50-C4633 50-C4634**	**50-C5632 50-C4633 50-C5634**	**YAW-2000C**	**YAW-5000C**
Capacity kN	2000	3000	8-2000	200-5000
Platens dia. mm	300	300	400	400
Ram travel mm	50	50		
Max. Vertical daylight mm**	350	350	500	500
Horizontal daylight mm	350	370		
For specimen size: cubes cm cylinders dia. X h cm	10, 15, 20 10x20, 15x30, 16x32	10, 15, 20 10x20, 15x30, 16x32		
Overall dimensions (lxdxh)mm	920x440x1100	1010x500x1200	800X580X1650	1150X900X3000
Weight approx. Kg	900	1120	2300	8500
Price approx. (Rs.)			280000-1050000/set	

* *To be adjusted using the suitable distance pieces.

Table 5.2: Compression Testing Machine Specifications available in the market

5.3 Flexure Testing Machine

Main Features:

- 50 kN max. capacity
- Large horizontal span:
- 520 mm
- Infinitely variable test
- speed: 0.1 to 51 mm/min
- DC motor 1,1 kW
- (53-C5/A model only)
- Voltage 230 V, 50-60 Hz, 1 ph
- Also available for 110V,60 Hz

Fig.5.2:53-C0005/A MULTIFLEX motor operated machine.

Fig.5.3: 53-C0004/A hand operated version.

Technical Data:

Max capacity	kN	50
Test Speed range(infinitely variable)	mm/min	0.1 to 51
Fast approach speed	mm/min	40
Max ram travel	mm	100
Horizontal span	mm	520
Vertical span between bearers	mm	285 - 700
Span between lower bearers	mm	50 - 500
Standard bearers		Dia. 38 mm x 500 mm Long
Measuring sensor	kN	10 load ring with stem break feature
Power rating	Watt	1100
Net weight	kg	137
Dimensions (l x w x h)	mm	632 x 495 x 1284

Note: All data except the test speed and power are both for the 53-C5/A and 53-C4/A versions.

Table 5.3: Flexural Testing Machine Specifications

5.4 Shake Table :

Performance data of six degrees-of-freedom shake tables.

Table size w/o table extension:	3.6 meter x 3.6 meter
Table size w/o extension platform in place:	7 meter x 7 meter
Maximum specimen mass:	50 ton maximum / 20 ton nominal
Maximum specimen mass with table extension platform in place:	40 ton maximum
Maximum Overturning Moment:	46 ton meter
Maximum Off Center Loading moment:	15 ton meter
Frequency of operation:	0.1-50 Hz nominal/100 Hz maximum
Normal Performance:	X axis Y axis Z axis
Stroke:	±0.150m ± 0.150m ± 0.075m
Velocity:	1250 mm/sec 1250 mm/sec 500 mm/sec
Acceleration:	±1.15 g ± 1.15 g ± 1.15 g (w/20 ton specimen)

Table 5.4: Shake Table Specifications

5.5 Reaction Walls

Specifications:

The test floor is a reinforced concrete box girder 14.40 m long, 12.00 m wide. The thickness of the top test floor slab is 2.40.m.

Fig. 5.4 : Reaction Walls

5.6 Actuators

Specifications:

The capacities of these actuators are listed in table below.

Actuator Model	MTS Quantity	Stroke (mm)	Tension Force (kN)	Compression Force (kN)
243.40T	5	762	291.4	496.4
243.45T	2	1016	445.0	649.0
244.41T	1	508	500.0	500.0
244.51S	2	508	1000.0	1000.0
243.90T	1	508	2002.0	2669.0

Table 5.5: Actuators available in the market

5.7 Sensor

Specifications:

Table 5.1 and 5.2 give an overview of some sensors. As it can be seen, there are far more active sensors on the market than passive sensors, which is limited to SP sensors.

Sensor name	C	f_o	Dam	Mas	R_g	CDR	R_c	G	K	Dyn	Mov
Mark products L4C	1	1.0	0.28	1.0	5500	8905		276			6.2mm
Mark products L4A	1	2.0	0.28	0.5	5500	8905		276			
Geotech S-13	1	1.0		5.0	3600	6300	23	629	0.198		3.0mm
Geotech S-13J	1	1.0		0.9	6400		20	344		140	1.5mm
Kinemetrics Ranger SS1	1	1.0	0.07	1.45	5000	6530	100	345	0.40		
Mark products L22	1	2.0						88			
Mark products L28B	1	4.5	0.48	0.02	395		---	35	---		2.0mm
Sprengnether S6000	3	2.0		0.5	280			45	0.44		
Geo Space GS-11D	1	4.5	0.34	0.023	380		---	32	---		1.8mm
Input/Output SM-6	1	4.5	0.26	0.016	375		---	28	---		4.0mm

Table 5.6: Overview of some passive sensors available in the market.

Abbreviations are:

C	: Number of components,
f0	: Natural frequency (Hz),
Dam	: Open circuit damping,
Mas	: Mass (kg),
Rg	: Generator coil resistance(ohm),
CDR	: Critical damping resistance (ohm),
Rc	: Calibration coil resistance (ohm),
G	: Generator constant (V/ms-1),
K	: Calibration coil motor constant (N/A),

Dyn : Dynamic range (dB),
Mov : Free motion of the mass (mm).

Name	C	f-range	Out V	In V	I	G	W	Dyn. Range	Resolution
NEGATIVE FEED BACK									
Lennartz LE-1D	1	1.0-80	----	12	3	400	1	120	3nm/s,1Hz
Lennartz LE-3D/5s	3	0.2-40	----	12	9	400	7	120	1nm/s,1Hz
Lennartz LE-3D/20s	3	0.05-40		12	50	1000	7		2nm/s,1Hz
Kinemetrics WR –1	1	0.05-20							
Geotech KS-10	1	0.05-20				500	3	140	< NLNM
ACCELEROMETERS									
Kinemetrics FBA-23	3	DC-50	2.5	±12	15	2.5	2	135	
Kinemetrics EpiSensor	3	DC-200	10t	12	35	2.5		155	
Sprengnether FBX23	3	DC-50	10	±12	30	10	1	90	11µg
Sprengnether FBX26	3	DC-50	10	±12	18	10	1	135	0.4µg
Geotech PA-22	3	DC-50	4.5	±15	40	2.25	5	114	10µg
Güralp CMG-5	3	DC-80		12	80		5		
Eeantec EA-140	3	DC-100	5.0	12	30	5.0		140	2µg
VELOCITY BB									
Nanomtrics Trillium	3	0.033-30	10	12	33	1000	11		< NLNM
Sprengnether S-3000Q,	1-3	1.0-250		±12	11	278	2		
Streckeisen STS-2	3	0.033-	-	12	150	1500			< NLNM
Streckeisen STS-1	3	0.0028-		12					
Sprengnether WB 2023	3	0.03-20	36	12	18	1000	5		> NLNM
Sprengnether WB 2123	3	0.016-50	36	23		1000	5		< NLNM
Geotech KS-2000	3	0.01-50	10	12		2000	7	160	< NLNM
Geotech KS-54000 IRIS(1)	3	0.003-5	20	24	100	2400	66		< NLNM
Güralp CMG-1	3	0.003-50		12	60		14		
Güralp CMG-3	3	0.01-50		12	75		8		
Güralp CMG-3T	3	0.01-100	10	12	245				
Güralp CMG-40	3	0.03-50		12	50	9			> NLNM
Güralp CMG-40T	3	0.03-50	10	12	50	3200	5	145	> NLNM
Eentec P-123	3	0.1-50	10	12	19	2000	5	130	

Table 5.7 Overview of some active sensors available in the market.

Abbreviations are:

C	: Number of components,
f-range	: Frequency range in which the response is flat (Hz),
Out V	: max voltage out (0-p,V),
In V	: Supply voltage (V),
I	: Current used (mA),
G	: Generator constant (V/ms-1 or V/g),
W	: Weight of sensor (kg),
Dyn	: Dynamic range (dB).

Resolution in last column can be given in nm/s, acceleration or whether the noise curve is above or below NLNM for most of the pass band. Most sensors are weather resistant, have some kind of calibration input and have a damping close to 0.7. Many sensors have several options and a typical has been selected. The power consumption is at 12 V so even if the sensor requires ±12 V, the current equivalent to 12 V has been given.

5.7.1 Which sensor to choose:

The number of sensors on the market is vary large and range in price from $50 for the one component geophone to $35000 for the best one component BB sensor, while the 'average' 3 component sensor cost around $2000-$4000. Earlier most sensors were passive, but now only passive SP sensors are sold. The tendency is clearly to produce more active sensors and there is now a large range of active sensors available based the principle already described (FBA or negative feedback). This does not mean that there is something wrong with passive sensors; they are just too expensive to produce (and cannot be made for very low frequencies). For the price of 3 passive 1 Hz 'average' sensors, a decent BB sensor going down to 0.03 Hz can be bought. So for 3 component SP installation, passive sensors have almost been squeezed out of the market.

CHAPTER 6

CONCLUSION

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CONCLUSION

After studying and visiting the earthquake facilities in the topmost institutions of India, any engineering institution can establish or develop its earthquake engineering laboratory according to the laboratory needs, requirements, and available funds of the institution. The instruments/machines which are necessary and essential to perform the seismic studies are discussed here so that the institution can build up an objective for:

- Advancing experimental and numerical simulation technologies: Construct and maintain the experimental facilities. Provide hardware, software and technical support to researchers and practitioners on earthquake engineering simulations;

- Developing and applying earthquake loss estimation technologies;

- Developing seismic design, evaluation and retrofit technologies: Advance seismic design, evaluation and retrofit technologies and code provisions for buildings and bridges to ensure structural resilience, and mitigate life and property losses during earthquakes;

- Developing state-of-the-art seismic technologies: Conduct researches on innovative, environment-friendly, and intelligent construction materials, technologies, and systems.

We must carefully evaluate the need and requirement of the earthquake laboratory earthquake laboratory and then chose the appropriate more efficient, cost-effective and environmentally safer instrument for the laboratory.

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