Volume IV Number 4

Bulletin of the Indian Society of Earthquake Technology

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DECEMBER, 1967

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BULLETIN OF THE INDIAN SOCIETY OF EARTHQUAKE TECHNOLOGY

Aims and Scope

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The Bulletin of the Indian Society of Eathquake Technology, covering all aspects of earthquake technology presents a cross section of technical papers, reviews, comments and discussions in the field of earthquake technology, news of the Society, serving as a medium for recording recent research and development work.

Publication

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Printed by Gautam Printing Press, Roorkee, (U.P.)

Bulletin of the Indian Society of Earthquake Technology, Vol. 4, No. 4, pp. 1–6. December, 1967

Bulletin of the Indian Society of Earthquake Techology

Vol. 4 December, 1967 No. 4

SINGLE DEGREE FREEDOM SYSTEM WITH AN ASSEMBLAGE OF VIBRATION ABSORBERS UNDER SINUSOIDAL EXCITATIONS

Y. P. Gupta* and A. R. Chandrasekaran**

Synopsis

Vibration absorbers have so far been used with machines and machine foundations subjected to sinusoidal excitations. In such cases a single absorber is required to reduce the large amplitude of vibration of primary system at resonance. In this paper the influence of providing multiple vibration absorbers has been presented. Experimental and analytical investigations were carried out for a single degree freedom system with an assemblage of vibration absorbers. The two results, analytical and experimental, compare very well with each other.

Introduction

The influence of single absorber on the response of basic single degree freedom system has been studied by several authors. To find the effect of multiple vibration absorbers in reducing the response of primary system, experimental and analytical investigations have now been carried out. Sinusoidal excitations were chosen for the test since these can be easily produced in laboratory with the help of mechanical oscillator. For the experiment, portal frame was selected as the basic system as it is a simplified type of framed structure and can be approximated as single degree freedom system. Steel was chosen as the material for frame because of its linear properties over a large range. Absorbers were also made of steel leaf springs.

Free and forced vibration response of frame with and without absorbers was recorded and response curves were drawn. Several combinations of absorbers with the basic system were tried. Analytically the response was determined by writing equations of motion and solving them with the help of numerical techniques. The two results were well in accordance with each other.

An assemblage of vibration absorbers is effective not only at one exciting frequency but at several other frequencies also. The response of parent system further decreased with the increase in number of absorbers.

The Model

A model of single bay portal frame made of steel (as shown in fig. 1) was fabricated. It was mounted on a shaking table, which could have horizontal motion in one

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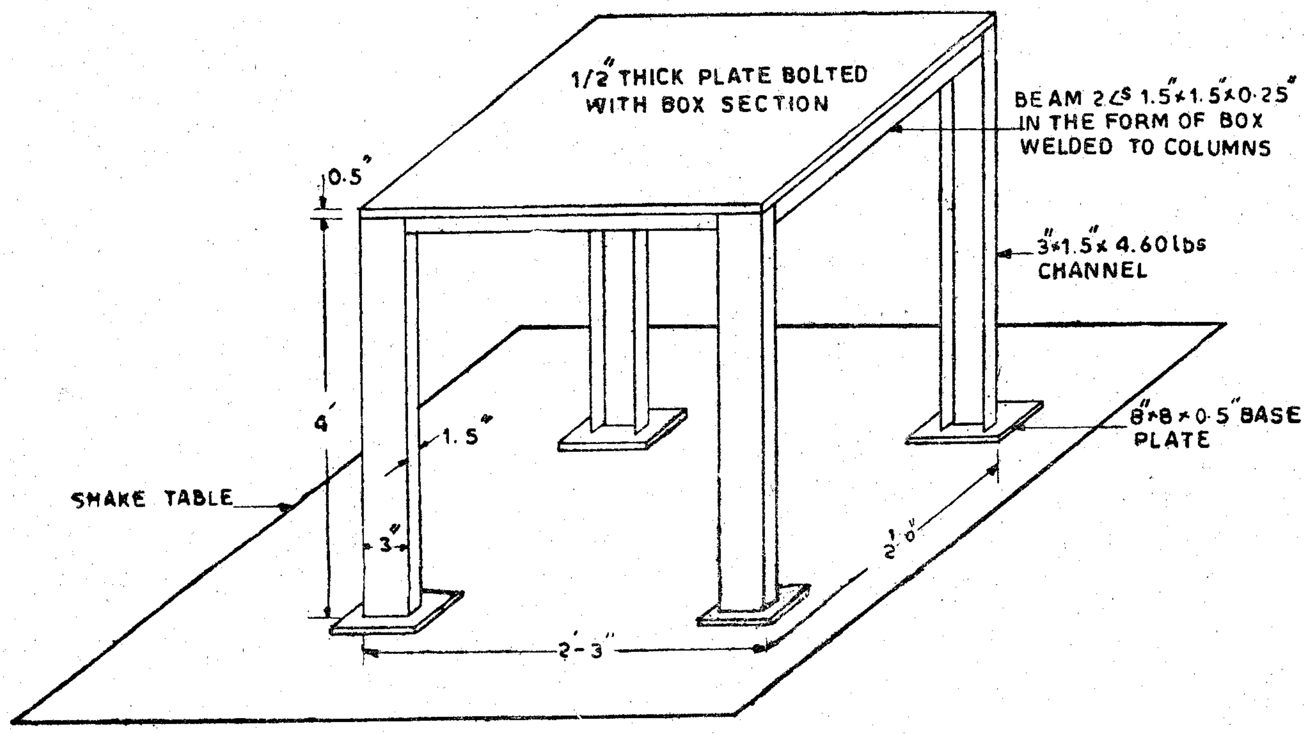


Fig. 1. Model of Portal Frame Mounted on Shake Table

direction. Vibration absorbers were made of steel leaf springs with concentrated mass at one end as shown in fig. 2.

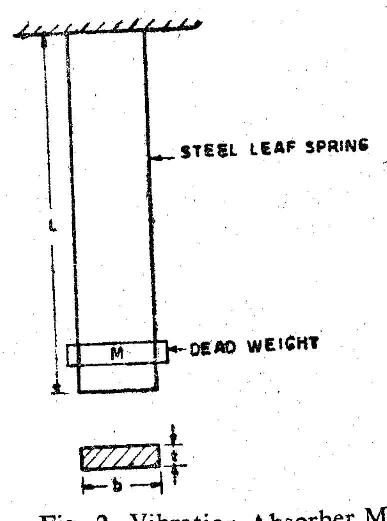


Fig. 2, Vibration Absorber Made of Steel Leaf Spring

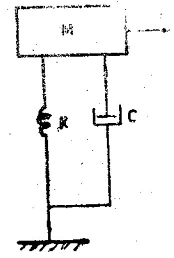


Fig. 3. Equivalent SDF Model

Experimental Setup

The model alone as well as with several combinations of absorbers, was excited on a shake table. The shake table was given motion by a mechanical oscillator driven by variable speed D C. motor. The oscillator works on the principle of two eccentric masses rotated in two opposite directions. The centrifugal forces get added up in one direction and get cancelled in the other perpendicular direction. Thus it gives vibratory force either in horizontal direction or in vertical direction depending upon the mounting position of oscillator.

The accelerations of table, frame and absorbers were picked up by acceleration pickups. The pickup was connected to a bridge circuit and the output of bridge was amplified by a Universal amplifier. The amplified signal output was recorded on an ink writing oscillograph. An experimental run consists of measuring the accelerations for various exciting frequencies.

Free Vibration Behaviour of Frame and Absorbers

The frame as well as absorbers can be represented by an equivalent single degree freedom system as shown in fig. 3.

Free vibration record of the system was taken after giving initial displacement to the mass Record was taken with the help of a pickup, amplifier and ink writing oscillograph. The following frequencies and damping properties of frame and absorbers were found from free vibration records.

TABLE 1

System	Frequency c/s	Percentage of Critical Damping	Equivalent lumped mass lbs.
Frame	8.58	0.625	180.00
Abs. 1	8.60	1.272	27.50
Abs. 2	9.25	1.200	27.50
Abs. 3	9.92	1.110	27.50
Abs. 4	10.30	1.070	27.50

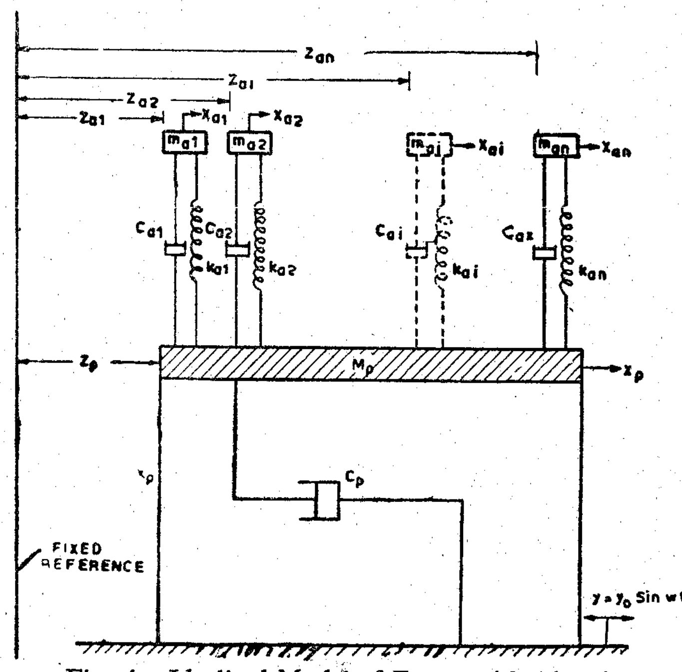


Fig. 4. Idealised Model of Frame with Absorbers

Response of Model to Sinusoidal Excitations

(A) Experiment

The accelerations of table base, frame and absorbers were measured for various exciting frequencies Several runs were made with different combinations of vibration absorbers with the parent system. Response curves for acceleration ratio versus frequency ratio were plotted. Acceleration ratio is the acceleration of frame or of absorbers divided by acceleration of table at any time and frequency ratio is the exciting frequency divided by natural frequency of frame alone.

(B) Analysis

The mathematical model of frame with absorbers is shown in fig. 4. The equations of motion for this model can be written as follows :

$$m_p \ddot{x}_p + (c_p + c_{a1} + c_{a2} + \ldots c_{an})(\dot{x}_p - \dot{y}) - c_{a1}(\dot{x}_{a1} - \dot{y}) - c_{a2}(\dot{x}_{a2} - \dot{y}) \ldots c_{an}(\dot{x}_{an} - \dot{y})$$
$$+ (k_p + k_{a1} + k_{a2} + \ldots k_{an})(x_p - y) - k_{a1}(x_{a1} - y) - k_{a2}(x_{a2} - y) \ldots k_{an}(x_{an} - y) = 0$$

$$m_{a1} \ddot{x}_{a1} - c_{a1}(\dot{x}_p - \dot{y}) + c_{a1}(\dot{x}_{a1} - \dot{y}) - k_{a1}(x_p - y) + k_{a1}(x_{a1} - y) = 0$$

$$m_{a2} \ddot{x}_{a2} - c_{a2}(\dot{x}_p - \dot{y}) + c_{a2}(\dot{x}_{a2} - \dot{y}) - k_{a2}(x_p - y) + k_{a2}(x_{a2} - y) = 0$$

$$\ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots$$
$$\ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots$$

$$m_{an} \ddot{x}_{an} - c_{an}(\dot{x}_p - \dot{y}) + c_{an}(\dot{x}_{an} - \dot{y}) - k_{an}(x_p - y) + k_{an}(x_{an} - y) = 0 \qquad (1)$$

where,

m_p — lumped mass of parent system.
c_p — damping constant for parent system.
k_p — stiffness of parent system.
m_a — lumped mass of absorber.
c_a — damping constant for absorber.
k_a — stiffness of absorber.
y — base motion.
x_p — displacement of mass m_p.
x_a — displacement of mass m_a.

Equation 1 can be simplified and written in the matrix form as follows :

$$\{\ddot{Z}\} + [D]\ \{\dot{Z}\} + [S]\ \{Z\} = -\ \{\ddot{y}\} \tag{2}$$

where,

$$[D] = 4\pi \begin{bmatrix} \left(\frac{\zeta_p}{T_p} + \frac{\alpha_{a1}\zeta_{a1}}{T_{a1}} + \frac{\alpha_{a2}\zeta_{a2}}{T_{a2}} + \dots + \frac{\alpha_{an}\zeta_{an}}{T_{an}}\right) & -\frac{\alpha_{a1}\zeta_{a1}}{T_{a1}} & -\frac{\alpha_{a1}\zeta_{a2}}{T_{a2}} & \dots & \frac{\alpha_{an}\zeta_{an}}{T_{an}} \\ -\frac{\zeta_{a1}}{T_{a1}} & \frac{\zeta_{a1}}{T_{a1}} & & & \bigcirc \\ -\frac{\zeta_{a2}}{T_{a2}} & & \frac{\zeta_{a2}}{T_{a2}} & & \\ \vdots & & & \vdots & \\ -\frac{\zeta_{an}}{T_{an}} & \bigcirc & & & \frac{\zeta_{an}}{T_{an}} \end{bmatrix}$$

$$[S] = 4\pi^2 \begin{bmatrix} \left(\frac{1}{T_p^2} + \frac{\alpha_{a1}}{T_{a1}^2} + \frac{\alpha_{a2}}{T_{a2}^2} + \dots + \frac{\alpha_{an}}{T_{an}^2}\right) & -\frac{\alpha_{a1}}{T_{a1}^2} & -\frac{\alpha_{a2}}{T_{a2}^2} & \dots & -\frac{\alpha_{an}}{T_{an}^2} \\ -\frac{1}{T_{a1}^2} & \frac{1}{T_{a1}^2} & & & \bigcirc \\ -\frac{1}{T_{a2}^2} & & \frac{1}{T_{a2}^2} & & \\ \vdots & & \bigcirc & \vdots & \\ -\frac{1}{T_{an}^2} & & & & \frac{1}{T_{an}^2} \end{bmatrix}$$

$$\{Z\} = \begin{Bmatrix} x_p - y \\ x_{a1} - y \\ x_{a2} - y \\ \vdots \\ x_{an} - y \end{Bmatrix}, \qquad \{\ddot{y}\} = \begin{Bmatrix} \ddot{y} \\ \ddot{y} \\ \vdots \\ \ddot{y} \end{Bmatrix}$$

and dot representing differentiation with respect to time. Also,

$\alpha_a = m_a/m_p$, mass ratio.

$\zeta_a = c_a/2\sqrt{k_a m_a}$, fraction of critical damping in absorber.

$T_a = 2\pi\sqrt{m_a/k_a}$, undamped natural period of vibration of absorber.

$y = y_0 \sin \omega t$, sinusoidal base motion.

$\ddot{y} = - y_0\omega^2 \sin \omega t$, sinusoidal base acceleration.

$T_p = 2\pi\sqrt{m_p/k_p}$, undamped natural period of vibration of frame.

$\zeta_p = C_p/2\sqrt{k_p m_p}$, fraction of critical damping in frame.

A modified fourth order Runge–Kutta procedure has been used for the numerical solution of equation 2. Various combinations of the parameters of vibration absorbers as given in Table 1 were used along with the main frame data for the solution of equations. Acceleration response of various masses were calculated for various exciting frequencies. Response curves for acceleration ratio versus frequency ratio were plotted for main frame as well as for absorbers.

Results

Plot of amplification factor (μ_p) versus frequency ratio (η) for the frame alone is shown in fig. 5, where μ_p is defined as the ratio between maximum acceleration of the frame to that of the base, and η as ratio of exciting frequency to natural frequency of frame alone. It is seen that high amplification peak occurs at $\eta = 1$ which is termed as resonance.

Response curves for frame with one absorber are shown in figure 6. Curve 1 gives response of the frame showing two different peaks, one at about $\eta = 0.8$ and the other at $\eta = 1.2$. There is a sudden depression at $\eta = 1$ which was a very high peak in the earlier case when no absorber was used. This is because of the change in the natural frequency of vibration of the parent system by putting vibration absorber. Both peaks in this case have lesser amplification factor as compared to earlier case of no absorber.

In other cases two and three absorbers are respectively used along with the parent system. Response curves in these cases for frame and absorbers are shown in figures 7 and 8. In these cases the number of peaks increases, but because of the limitations in exciting frequency of the table, the full response curve could not be plotted. From these curves it is seen that amplitude of each peak is smaller than the amplitude in earlier cases. This shows that more number of absorbers are effective not only at one exciting frequency but at several other frequencies. Further, the peak amplitudes of parent system go down as the number of absorbers increases. Also from the response curves of absorbers, it is seen that peak amplitude of absorbers goes down as the number of absorbers increases.

Conclusions

The response of frame decreases with the use of vibration absorbers. The reduction is more if more number of absorbers are used Also the response of absorbers themselves decreases with the increase in number of absorbers. More number of absorbers are effective not only at one exciting frequency but at other frequencies also.

Acknowledgements

The Digital Computer work was carried out at S.E.R.C., Roorkee.

The authors are thankful to the Director, S.R.T.E.E., Roorkee, for providing facilities for experimental work.

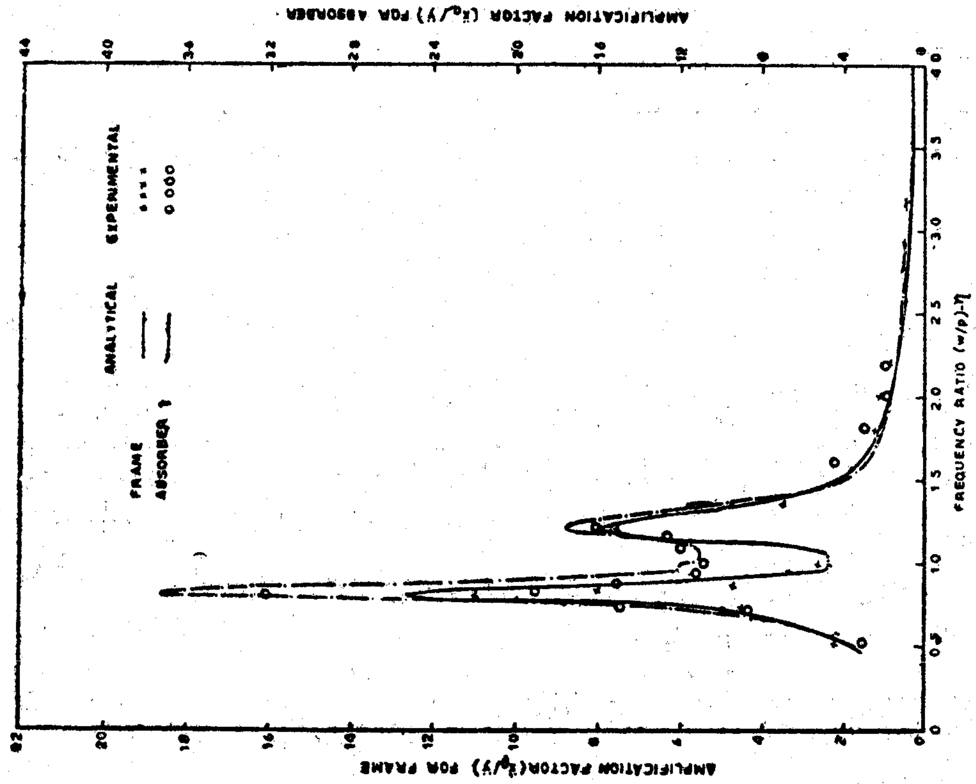


Fig. 6. Response Curvse for the Frame with Absorber 1

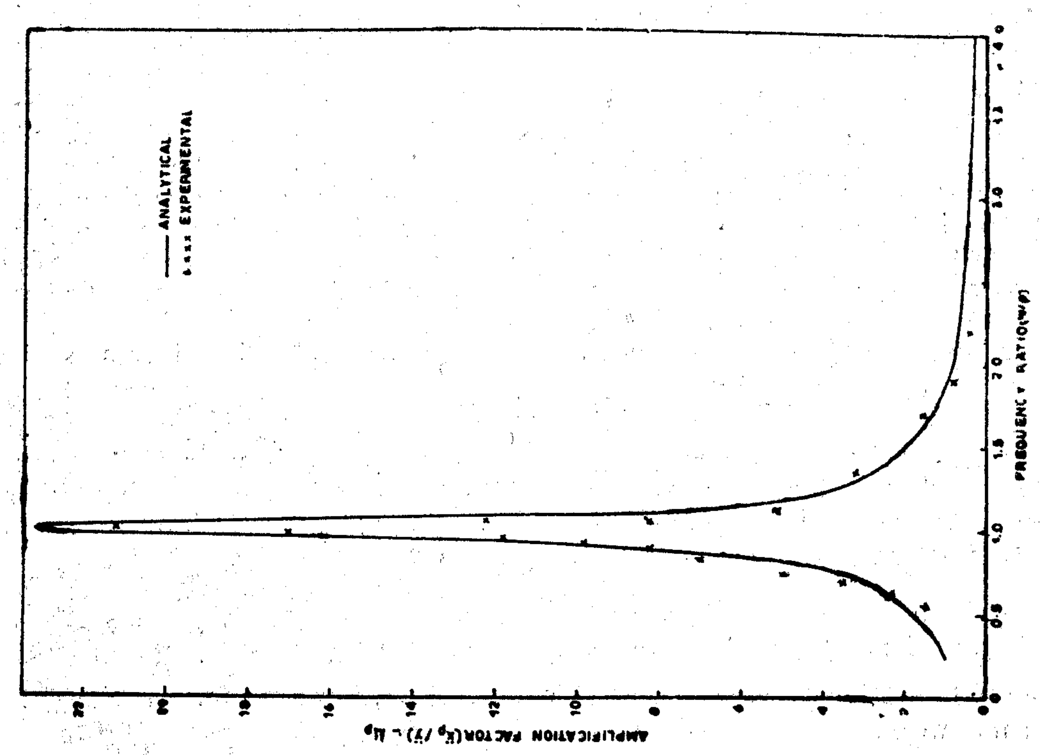


Fig. 5 Response Curve for Frame Alone

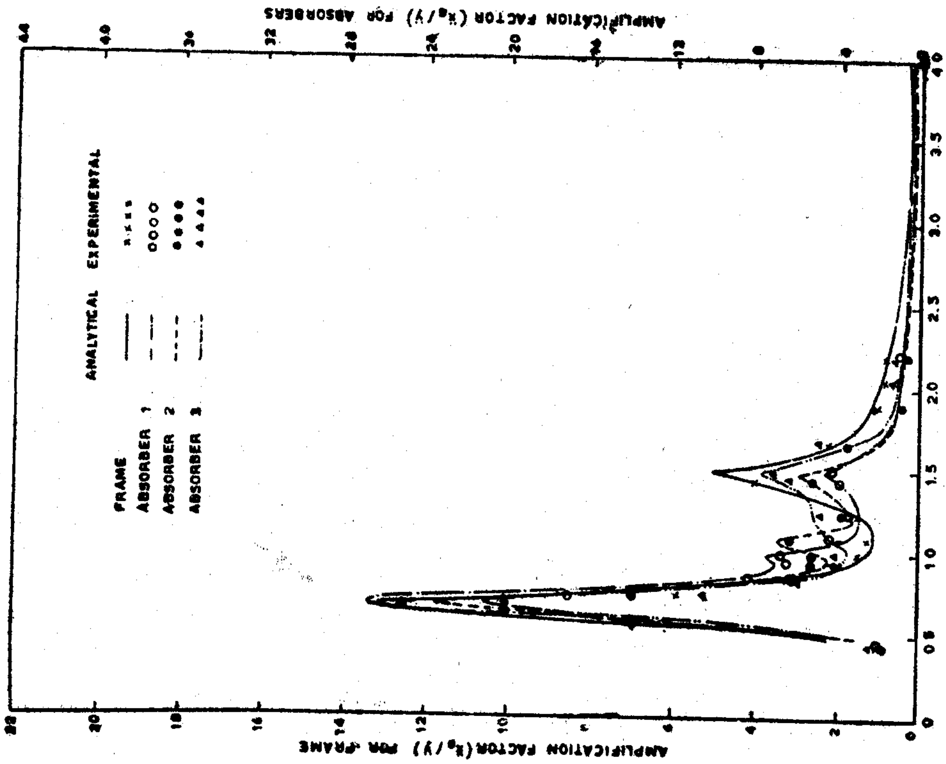


Fig. 8. Response Curves for the Frame with Absorber 1, 2 and 3

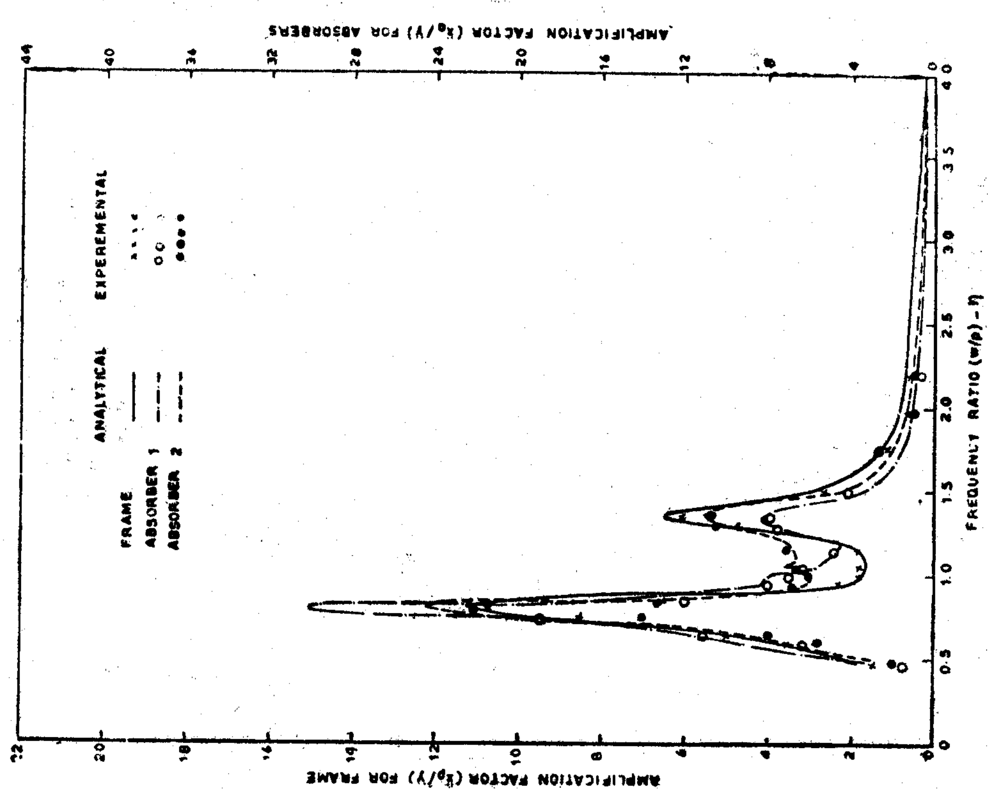
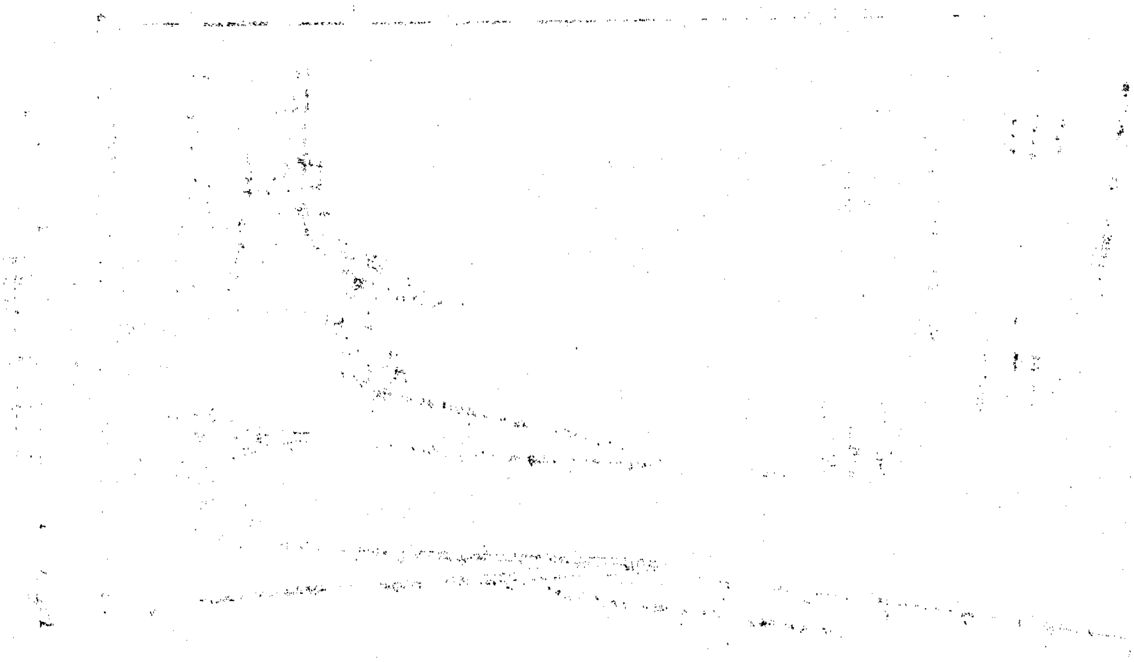
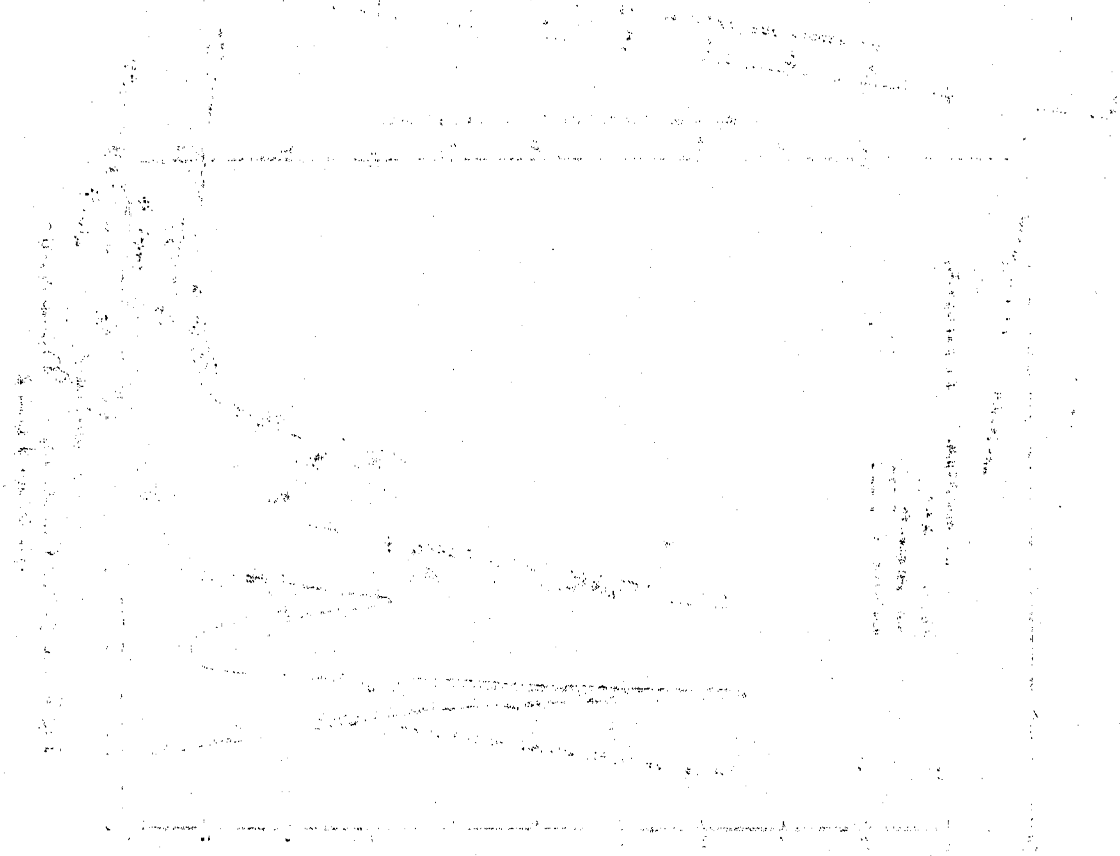


Fig.7. Response Curves for the Frame with Absorber 1 and 2





Bulletin of the Indian Society of Earthquake Technology Vol. 4, No. 4, pp. 9-11 December 1967

DETERMINATION OF SOIL CONSTANTS FOR DESIGN OF MACHINE FOUNDATIONS

Shamsher Prakash[1] and D. C. Gupta[2]

Soil constants used in the design of machine foundations can be determined from a simple test on a model cement concrete block A block of size 1.5 m × 0 75 m × 0.7 m high with its base resting on the surface of the soil is excited beyond resonance by subjecting it to a sinusoidally varying force by means of a mechanical oscillator. The oscillator is mounted on the top surface of the block (Figure 1) and is subjected to vertical vibrations. The amplitude of vibrations at different frequencies of excitation are recorded. Coefficient of Elastic Uniform Compression, Cu, is then calculated by the formula

$$Cu = \frac{\omega_{nz}^2\, m}{A} \text{ tons/m}^3 \qquad (1)$$

where ω_{nz} = Resonant circular frequency, radians/sec.

m = mass of the block (oscillator+motor), tons. sec^2/m

A = Base area of the block, m^2

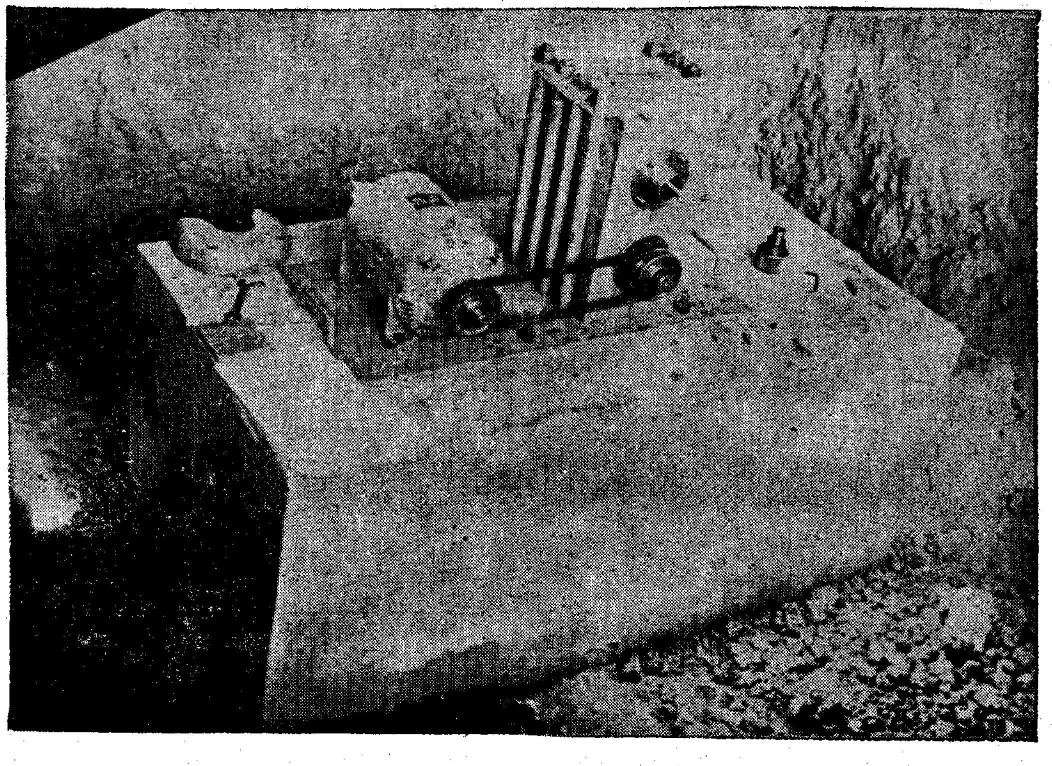


Fig. 1. Lazan Oscillator Mounted on Test Bloch

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However, it is relatively easy to excite the block to resonance in the longitudinal direction as the resonant frequency in this case is lower than that for vetical excitation. In case of longitudinal vibrations, the unbalanced force produced by the oscillator causes the foundation block to translate in the longitudinal direction as well as to have pitching about the transverse axis of the footing (Figure 2). The system thus constitutes a two degrees of freedom system having two natural frequencies. In practice, only the first natural frequency is generally achieved because of the limitations of the usually availalable equipment.

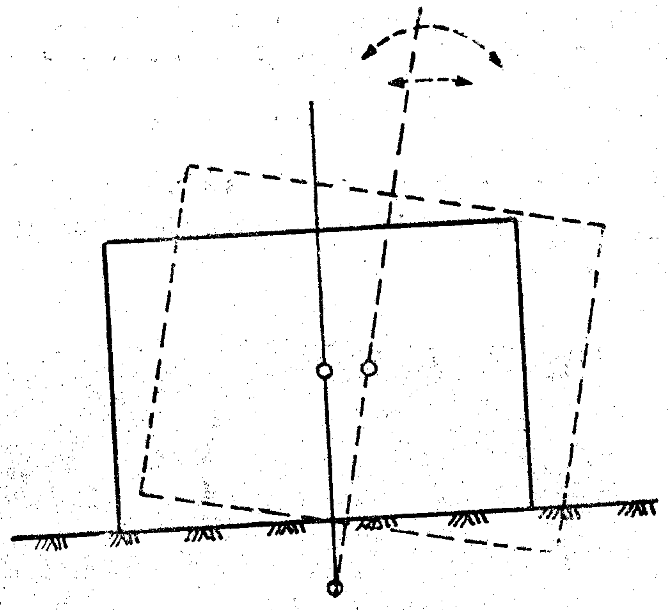

Fig. 2. The Block Vibrations in the First Mode-Sliding and Pitching in the Same Direction

Figure 3 shows a typical plot of amplitude versus frequency of excitation for longitudinal vibrations of the block, vibrations being measured at the top of the block on its side and along the direction of vibration. Assuming the following relationship between coefficients of Elastic non-Uniform compression ($C_\varnothing$) and Uniform shear (C_τ)*

$$C\phi = 3.46 \ C_\tau \tag{2}$$

the following expression is obtained for the natural frequencies :—

$$\omega^2_{n_{1,2}} = \frac{1}{2\gamma}\left[\left(\frac{A}{m} + \frac{3.46\ I}{M_{mo}}\right) \pm \sqrt{\left(\frac{A}{m} + \frac{3.46\ I}{M_{mo}}\right)^2 - \frac{13.84\ .AI}{m\ M_{mo}}}\right] \times C_\tau \tag{3}$$

where I = Moment of Inertia of the base area w r.t. axis of rotation.

M_m = Mass M.I. of system about an axis passing through C.G. of the system.

M_{mo} = Mass M.I. of system about an axis passing through C.G. of the base.

$\gamma = M_m/M_{mo}$

Equation (3) for the block of above dimensions reduces to

$$\omega^2_{n_{1,2}} = 4.96\ C_\tau \text{ and } = 22.35\ C_\tau \tag{4}$$

*Barkan, D. D., (1962) "Dynamics of Bases and Foundations", McGraw Hill Co., New York, N.Y. p-40.

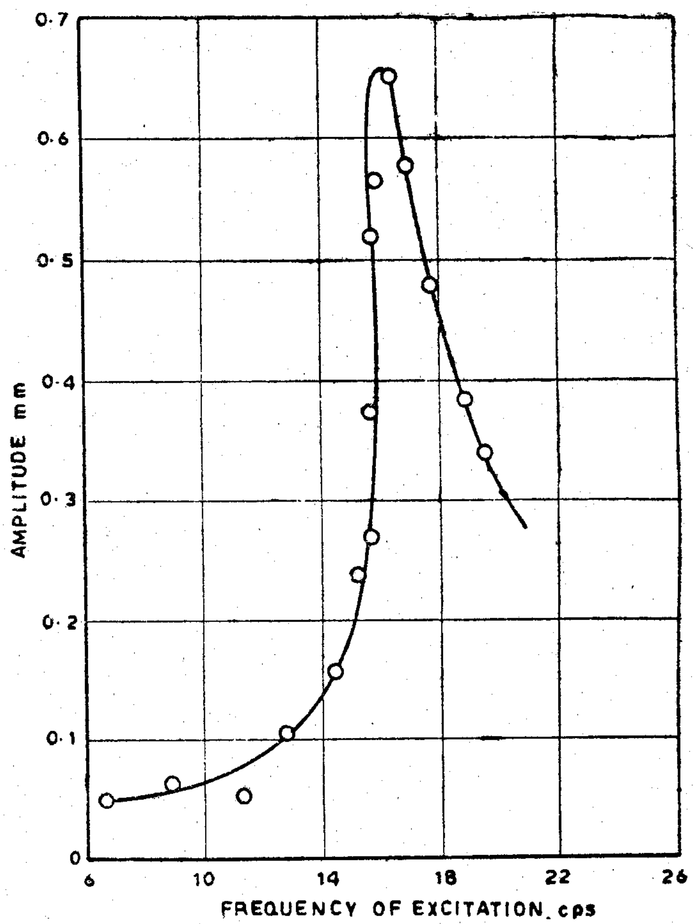

Fig. 3. Amplitude Vs Frequency–Location 1 (IEL Kanpur) (Pickup at Top)

Having determined the lower natural frequency experimentally, the value of C_τ can be computed form Equation (4). The value of Cu may then be calculated from the following relationship proposed by Barkan

$$C_u = 2\, C_\tau \tag{5}$$

This approach was adopted in determining the relevant soil constants for design of compressors of the Fertilizer Factory of Indian Explosives Ltd. (ICI), Kanpur and Forging Hammer Foundations of Jamna Auto Industries, Yamunanager and M/s Forgings Private Ltd, Faridabad and at a few other locations.

Bulletin of the Indian Society of Earthquake Technology, Vol. 4, No. 4, pp. 13-18. December, 1967

IMPORTANCE OF EARTHQUAKE STUDIES AS PART OF ENGINEERING GEOLOGY INVESTIGATIONS IN COUNTRY-PLANNING*

L. S. Srivastava†

Abstract

The paper lays stress on the importance of earthquake studies in active parts of the world and emphasises the need of detalied geological investigations assisted by close net work of seismological observatories, for demarcation of the seismic belts. For earthquake resistant construction it is necessary to have the knowledge of the nature of strong ground motion near the site of a proposed structure, and the force that the structures having different dynamic characteristics will be subjected to within short distances from the epicentre. It is therefore considered essential that stations should be established to house instruments to record strong motion and response of structures having different dynamic characteristics. The data obtained will help in evaluation of seismic coefficients and theoretical and experimental studies to study the behaviour of the ground and the structure for providing adequate safe guards against damage during earthquakes.

Introduction

Earthquakes are being felt since times immemorial, and it is estimated that more than 300,000 earthquakes occur every year in various parts of the world, though only five to six thousand are felt by the people and about twenty five are classed as catastrophies. The loss of life and property has varied considerably according to the place and time of occurrence and the size of the earthquake.

Active earthquake belts cover large segments of the earth and there are few areas where earthquake problems can be totally neglected. The greatest number of earthquake foci are found to be concentrated in the Circum-Pacific belt and the belt which extends from North Africa, through Southern Europe, the Alps, South Eastern Europe and Asia Minor, to the Hindukush, Central Asia and the Himalayas, and thence to Indonesia where it joins the Circum-Pacific belt. It is in these belts that the geologists and the engineers are faced with the most challenging and continuing problem of protecting mankind by taking necessary precautions in the construction of structures and allowing earthquake forces in their design.

The fundamental aims of earthquake engineering are to prevent personal injury and loss of human life, to minimise damage to property and to ensure the continuity of vital services in the event of earthquake. Usually structures are designed by taking in certain proportion of its weight (usually 10% g) acting at its centre of gravity as equivalent to an earthquake force and many structures designed on this thumb rule have withstood shocks of moderate size. This thumb rule has limited application and it is desirable that design of seismic coefficients for structure are estimated after consideration of the seismicity of the site, dynamic response characteristics of the structure including the interaction of the structure and the sub-soil, energy absorption or damping of the structure, properties of structural materials, bearing capacity of the soils and other factors which control the over all behaviour of the structure and the importance of the structure as related to its use and permitted degree of damage. Thus to arrive at a conservative estimate of the design seismic

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* Accepted for presentation at the XXIII session of the International Geological Congress in Prague 1968. Printed with the permisison of the Secretary General, International Geological Congress, XXIII session, Prague, Czechosslovakia.

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coefficients and proper site selection, in addition to the data of the characteristics of the structures and construction material, adequate knowledge of strong ground motion data on past earthquakes and resulting damage and geographic, geotectonic, geological and sub-soil condition is essential.

Seismicity

Seismicity is a term used to describe the form and status of earthquake activity in an area. Data on geology, tectonics, and the frequency, epicentral distribution, magnitude and intensity of past earthquakes form the basis in expressing the earthquake risks involved; and various kinds of maps are prepared to evaluate the probability of occurrence of earthquake and its likely maximum intensity in the area.

Unfortunately, systematic records of earthquakes have been obtained only since very recent times. Before the advent of instrumental measurements, it is only the very devastating shocks that are mentioned in historical records. Detailed descriptions are available only for earthquakes that have occured in the present century. and records of thousands of earthquakes which may have occurred earlier are not available. At present more than four hundred seismograph stations are operating in the various parts of the world. But even now many small tremors, orginating from the potential active zones along which a devastating earthquake could occur in future, are missed, as the net work of the stations is not close enough and the waves die off before they reach a recording station. A closer net work of seismograph stations would thus be very helpful in the study of active belts by recording greater number of smaller shocks occurring frequently for country planning (4).

In many cases, in the absence of seismic data it is difficult to demarcate the active belts and prepare seismic zoning maps. In such cases data on tectonics of the region can be utilised as seismicity has close correlations with geology and tectonics, The application of this correlation is not fully understood and is complicated. Still, it is necessary to study not only the present existing geological structures, but also the complete history of the tectonic evolution of the area, through the various geological ages and with particular reference to the recent differential movements of the crust. Geological mapping, geophysical surveys, geomorphological data and geodetic measurements assisted by seismological records thus help in recognising and demarcation of the active faults and zones of differential movements along which earthquakes can be expected to occur in future.

Strong Motion Earthquake Study

There are two principal types of seismograph stations in common use, generally referred as 'teleseimic' and 'local'. The primary purpose of the teleseismic stations is to record earthquakes from long distances. The main problems of study at such stations are delineation of areas of high seismicity, crustal structure, interior of the earth, mechanism of earthquakes and tsunami warning. Although the larger earthquakes can be recorded at very great distances from their foci, but their study alone is insufficient for the proper understanding of the processes involved. Small earthquakes are proportionately more common than the larger ones, and their study often allows a more rapid determination of the nature and extent of an active belt as compared to the major shocks. Local stations are thus very essential and are more helpful in determination of the pattern of seismicity and its correlation with geology, regional crustal structure, precise magnitude and epicentre of the earthquakes, ground movements in the epicentral tracts, general character of ground formations and the vibration characteristics of the ground motion.

The seismograph station maintain sensitive seismographs and the requirements of the various studies need these instruments to be located on firm ground (preferably rock) isolated from inhabited areas to avoid disturbances caused by local effects. If a strong motion, enough of engineering significance occurs within 50 to 100 kms. radius of these sensitive instruments they are thrown off the scale and cease to function. Such stations do not thus provide adequate data for engineering studies.

For the design of earthquake resistant buildings, factories, bridges, dams etc. an engineer requires data of true ground movements and acceleration due to earthquakes within a distance of 50 to 100 kms. from the site of the proposed structure, and also the response of structures to these movements, because this earthquake only could damage the structures that are to be designed and constructed. Special strong motion instruments, are therefore necessary, to record the character of these movements for the correct determination of stresses and deformations produced. These would also be helpful in evaluating the influence of the local geological conditions on the earthquake motion.

The strong motion measurements are made on accellerographs (2). The true ground motion recorded as a function of time by the accellerograph (Fig. 1) help in determining the response of the structure and the preparation of response spectrum curves (1).

The desirable natural period of vibration of the accelerograph is about 0.05 second, but periods not greater than 0.10 second are acceptable for general use. Where it is known that short period motions are not important, the period may be kept as high as 0 15 second. The range of the accellerograph should be such that it can satisfactorily record a maximum acceleration of 1 0 g, and should be sensitive enough to accurately measure the smallest earthquake of engineering significance. The damping of the accelerometer element should not be less than 60% of the critical The recording speed should not be less than 10 mm per sec., and it is desirable that a uniform speed is maintained with an accuracy of the order of 5%. As strong motion earthquakes generally occur at intermittant intervals and due to the high speed of recording, continuous running of the accelograph is not possible and the instruments require a starting mechanism which must be triggered by the earthquake itself, with the recording paper drive initially at rest. The time delay between rest and full recording speed should not be greater than 0.1 to 0.2 seconds so that greater parts of the initial motions are not missed. The time duration of the record must be at least 30 seconds and the instrument should contain an automatic reset to return the instrument to readiness for the next earthquake. A sufficient supply of recording paper should be included to permit at least two repetitions of the recording cycles before servicing. The operating power of the accelerograph must be independent of local electric supply, which may be used for such purposes as charging of batteries. In the design of the accelerograph, due consideration should be given to the ease of installation and of maintenance in proper operation condition. It should also be kept in mind that such instruments may often have to be checked and serviced by relatively unskilled personnel.

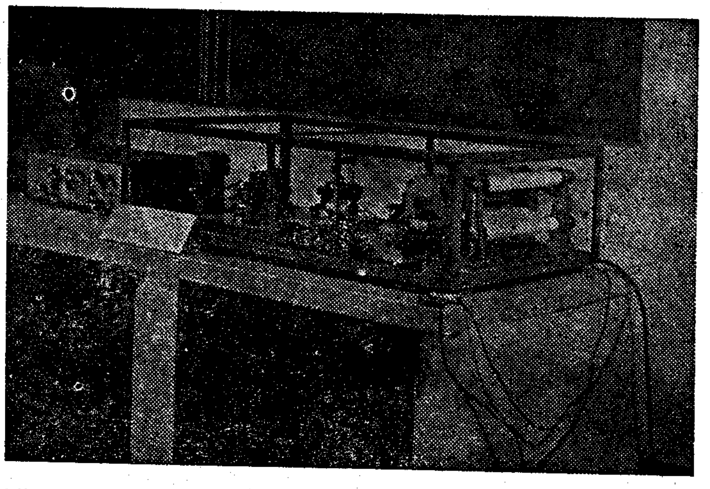

Fig. 1. A strong motion Acclerograph to measure strong ground motian

The accelerographs should be installed in a closer net work as compared to the standard seismograph net works, so that it can record ground motion of sufficient magnitude to be of engineering interest within 50 to 100 kms. of the epicentre of strong earthquakes. Also the magnitude of the ground motion may be strongly modified by local geological conditions which could change at very short distances, and therefore it is desirable to install the instruments in the geological and soil environments in which the engineering structures are envisaged to be built, since it would be very difficult and expensive to completely cover all the seismic regions with an entirely adequate net work of accelerographs.

Because of the relatively high cost and complexity of the strong motion accelerograph, and the necessity for obtaining more information of the effects of local geological conditions and greater instrumental coverage of seismic areas, a low cost simplified strong motion earthquake recorder has been developed, which has been termed as Structural Response Recordes (3) This recorder does not directly measure ground motlon, but rather records the maximum response of a mechanical system idealising the two major dynamic characteristics (natural period of vibration and damping) which affects the over all behaviour of a structure. The natural period and damping of the recorder element can be made similar to the period and damping of the important structures in the region in which the recorder is to be used. Typical values of natural periods which have been used are from 0.25 to 1.25 seconds and the usual values of damping are from 5 to 10% of critical. A group of structural response recorders installed in the vicinity of an accelerograph will give increased information on effects of the local geology and soil conditions.

It is useful to design structural response recorders with multiple elements, covering a range of periods and damping The recorders (Fig. 2) being installed in India consist of six elements having the following characteristics :

Pendulum No.	Period second	Damping % of critical
1	0 40	5
2	0.75	5
3	1 25	5
4	0.40	10
5	0.75	10
6	1.25	10

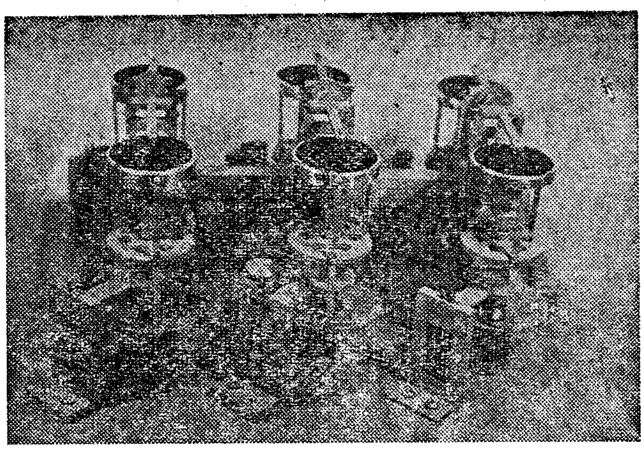

Fig. 2. Structurl Response Recorders designed and manufactured at the Earthquake School, Roorkee, India Structural Response Recorders have been installed at 37 stations in the seismically active part of India. Each set consists of six pendulums having different period of vibration and damping so that a fairly good idea of the response of the idealised structures during a strong earthquake can be obtained.

The record so obtained on the six elements directly give points on the response spectrum curves relating natural period, damping and response of the structure. This data is directly useful for design of structures with properties simulated in the recorder.

The reading of the recorders can be correlated in an approximate way with seismic intensity scales, as it takes into account the geological characteristics of the area which affect the propagation of waves and the effects due to the interaction between the ground, earthquake waves and the structures. The observed data hence provide a way of introducing an improved quantitative significance into such scales.

Prediction of Earthquakes

It would be praise worthy effort if it would be possible to predict earthquakes with respect to the place of cccurrence, time and its size. The work involved in this problem however, presents great difficulties, huge expenditure and is very difficult to achieve in the near future because of the lack of knowledge of the exact mechanism of earthquake occurrence. In Japan and U.S.A. extensive studies are being undertaken and crustal deformations, gravity anomalies in epicentral tracts, variation in seismic wave velocity in active belts and relation of seismic activity to variations in geomagnetic and earth currents are being studied (5). These studies have enabled to pin point the areas where earthquakes are expected to occur in future. But it has not been possible so far to estimate exactly the time of occurrence, or its exact location or its size. Unless the science is perfected, prediction may lead to very serious psychological and socio-economic problems. It will require huge organisation and finance to shift the population from a certain area in the expectation of an earthquake. Such efforts may be useless if the earthquake fails to occur at the predicted times or it shifts its occurrence a few miles away from the expected place or it happens to be of a size too small to need shifting of population. Perhaps it would be more appropriate to take precautions against the damage that an earthquake may cause rather than concentrate on its prediction. Even if a precise prediction is possible it would be essential to strengthen buildings and other structures which will be subjected to severe stresses during an earthquake. However it is very desirable to carry on the basic studies to give more information regarding the mechanism of earthquake occurrence and the factors that may lead to exact prediction.

Seismic Zoning

Though it is difficult to predict earthquakes, it is necessary to prepare seismic zoning maps and delineate zones where earthquakes of a certain probable maximum intensity are likely to occur. Such maps are of much help in the design and construction of earthquake resistant structures to withstand the particular earthquake intensity.

The construction of such maps require data on seismic and tectonic activity of the region. The seismic data consists of locations of foci, energy of earthquakes, frequency of earthquakes of different magnitudes or in case of insufficient data the maximum energy of a single earthquake, observed intensities, the dynamical characteristics and nature of the expected ground movements. This information can be obtained from seismographs and strong motion instruments and the past records. Especially, in regions where seismograph stations are not available, all available historical data concerning earthquakes should be compiled and analysed for the preparation of such maps. In some regions where only few earthquakes may have occurred to permit the demarcation of zones on seismic data alone, tectonic evidences have to be used for interpolation and extrapolation of seismic data. For convenience, it can be assumed that if earthquakes of a certain maximum intensity occur in a tectonic zone having a characteristic structure and geologic history, the earthquakes of the same maximum intensity may arise further along the whole length of the same zone or in another zone with similar structure and history. When data on tectonic conditions is not available probable seismic intensity could be assumed according to the biggest earthquake that occurred in the area, and as new geological data become available the level of estimated probable intensities could be reduced for parts of the region.

It is noted that earthquake epicentres are often concentrated along the boundaries between areas of different history of geological movements, active faults, or zones of differential movements. It is essential that regular geological mapping and special tectonic investigations are carried out in all such zones and the data so collected is combined with the seismic data. Active faults are often shown clearly on the air photographs and can thus be mapped comparatively rapidly. Zones of rapid differential (vertical and horizontal) movements can be mapped by a combination of geological, geomorphological, geodetic and geophysical methods.

In country planning or site selection for large engineering projects or townships, it is essential to prepare local seismic zoning maps to delineate sections of substantially different soil conditions and to determine the seismic intensity. It is now well established that the damage to buildings differs in different soil conditions and a close relation has been observed between damage of buildings and sub-soil condition during many strong earthquakes.

Detailed subsurface exploration should be carried out for the preparation of 'Geotechnical maps' showing the distribution of the various soil layers (on the surface and below the ground), their characteristics and the hydrological conditions. Classification of the ground should also be made, and soils which are reliable for supporting the structures be distinguished. Seismic coefficient for the various soil conditions should be evaluated. Based on this data standard recommendations for the type of foundations and structures to be adopted in the particular ground conditions can be evolved. This will also help in land use classification in regional planning of townships. Weak and soft ground susceptible to liquefaction and subsidence can be left as open spaces, thus avoiding the subsidence and tilting of structures in such soil conditions. Special considerations along active faults or zones of potential landslides could be adopted. In general homogeneous and firm subsoil are desirable for support of structures and soft, loose and saturated soils exposed to irregulaar or large settlements due to earthquakes should be avoided. The importance of local seismic zoning is being gradually realised, especially in the areas which are being planned to be developed as large scale industrial settlements.

Conclusions

Considerable progress has already been made in the understanding of seismic phenomena, and in taking adequate protective safeguards against earthquakes. However, there is still need of having closer net work of seismograph stations for the recording of both near and distant earthquakes and installation of strong motion instruments for recording ground motions of engineering significance. The records from such sta ions will permit the demarcation of the various zones of seismic activity. With the geological, tectonic and subsoil information, more detailed and accurate seismic zoining maps can also be prepared. Thus it is essential that in addition to the collection of seismic data, stress be laid on the study of regional tectonics of the region with special reference to the recent crustal movements. The data obtained from these studies will help in the evaluation of seismic coefficients and theoretical and experimental studies to study the behaviour of the ground and the structure for providing adequate safe guards against damage during earthquakes.

Acknowledgements

The author is grateful to Dr. R.S. Mithal, Professor and Head of the Geology and Geophysics Department, University of Roorkee, Roorkee, for going through the manuscript and for his valuable comments The paper is being published with the kind permission of the Director, School of Research and training in Earthquake Englneering, University of Roorkee, Roorkee, India.

Reference

1. Housner, G.W., R.R. Martel, and J.L. Alfrod, (1953), "Spectrum Analysis of Strong Motion Earthquake", Bull. Seism. Soc. of America Vol. 43, No. 2, April 1859.
2. Hudson, D E., (1959), "Ground Motion Measurements in Earthquake Engineering" First Symposium on Earthquake Engineering, University of Roorkee, Roorkee, February 1959.
3. Krishna, J., and A.R. Chandrasekaran, (1965), "Structural Response Recorders", Proceeding, Third World Conference in Earthquake Engineering, Auckland, New Zealand 1965.
4. Krishna, J. and L.S. Srivastava, (1966), "Importance of Earthquake Studies as part of Investigations for Power Projects", Bull. Indian Society of Earthquake Technology, Vol. III, No. 2, May 1966.
5. Proceedings of the US-Japan Conference on Research Related to Earthquake Predictive Problems, March 1964.

Bulletin of the Indian Society of Earthquake Technology, Vol. 4, No. 4, pp. 19–34. December, 1967

SYMPOSIUM ON KOYNA EARTHQUAKE OF 11 DECEMBER 1967 AND RELATED PROBLEMS

(Calcutta, June 1–2, 1968)

The area around Koynanagar, district Satara, Maharashtra State, witnessed a great earthquake in the early hours of December 11, 1967, and caused considerable loss of life and damage to the structures. The epicentre of the earthquakes was very close to the Koyna dam of the Koyna Hydro-Electric Project, and shook the western coast of India and the whole of Maharashtra State. Due to the great economic, industrial and strategic importance of the Koyna Projects, and the disaster it caused in the region, this earthquake has attracted great attention Detailed investigations have been carried out by the various organisations to study the damage to the structure, behavior of ground, seismological data and related problems and further studies are in progress.

The Indian Society of Engineering Geology, Calcutta, the Institution of Engineers (India), Bengal Centre, Calcutta, Mining, Geological and Metallurgical Institute of India, Calcutta and the Indian Society of Earthquake Technology jointly sponsored a "Symposium on Koyna Earthquake of 11th December, 1967 and Related Problems", which was held on June 1 and 2, 1968, in the hall of the Institution of Engineers (India), Bengal Centre, 8, Gokhale Road, Calcutta—20. This report of the symposium gives a commentry on the prediction and orign of the Koyna Earthquake, the Inaugural Address of Dr K. L. Rao, Minister for Irrigation and Power, Government of India, New Delhi and the abstracts of the various papers presented at the symposium.

KOYNA EARTHQUAKE

It is rather disconcerting that the Koyna earthquake of December 11, 1967, would still remain an unsolved problem. Devastating as it was, it appears to have also shattered the mythical stability of a crustal sector The damage to the reputation of the earth-scientists seemed to be more complete ; and the embarrassment to the bureaucrats was infinite. A lot has been written and spoken on the Koyna event and a lot more would come by. In time wounds would heal, the laymen would forget and the scare would recede. It may be a long time,—decades or centuries, till Koyna might rock again. Posterity would probably take care of that.

The most important issue is whether it was within human ability to predict this event or to know if such an event was possible in this area. The earth-scientists remain responsible for an answer.

Koyna is situated in a country underlain by about 2000 metres of basaltic lava flows. A monocinal warp (the Panvel flexure) is close to this region. The west coast is believed to be faulted one, the fault dating back to Miocene time. The west coast reveals a gravity high corresponding probably to a mantle upwarp. This is followed to the east by a pronounced low in the Koyna region. A linear system of hot springs in the neighbouring country lend evidence of above-average thermal activity. Shears and small dislocations are numerous in and around Koyna.

Koyna earthquake was an event of magnitude 6.5. The focus could be either at a depth of 8 kms or even at depths of 30-40 kms. Seismologists do not agree. Koyna had been trembling imperceptibly ever since the reservoir started filling up. The west coast has also experienced minor tremors. There was a perceptible shock on September 13, 1967. Rather fortunately instrumental installations in the Koyna Dam were sophisticated enough to permit detailed analysis of these events. Some correlation has also been claimed to exist between the effect of waterload on the shears and dislocations and the triggering of the tremors.

Geophysicists tend to confirm that the basaltic lava pile in the area rests on a crystalline basement offering greater resistance to elastic wave propagation.

This is the background from which the thoughts for future would be wrought.

We have travelled a long way from the classical 'elastic rebound' concept of Reid about the origin of earthquakes Matsuzawa's theory of the "earthquake field" provides a thermodynamic approach to the problem. Reid's apparently mechanistic theory failed to provide a satisfactory treatment of the boundry conditions in the medium ; but Matsuzawa's theory remains vague about the mechanics of the process

Recently Lomnitz (1964) suggested three approaches to the problem of earthquake studies. Earthquakes can be viewed as (a) stress transients, (b) process of energy release and (c) random stochastic events. These approaches are mechanical, thermodynamical and statistical respectively.

Contrary to normal belief, it appears to be reasonable that the ultimate origin of earthquake energy is in the internal heat pool of the earth. The earth can be considered as a heat engine driven by the thermal imbalance resulting from the difference between the actual temperature and the adiastrophic temperature. If earthquakes are caused by a process of thermal stress conversion in a continuous system it can be demonstrated that there could be no outstanding periodic fluctuations. Major earthquake periodicities would be likely in period ranges of decades or centuries and not in smaller periods.

The rate of heat transfer in the mantle by conduction/convection is not sufficient to cause appreciable stress accumulation in view of the stress relaxation rates in the mantle. With increasing depth there is less likelihood of storage of mechanical energy ; and such energy storage is only possible chemically. This can be released abruptly, as a result of spontaneous phase change. Since it has been demonstrated that explosions could also release energy as 'S' waves, the above process furnishes a better explanation of the mechanism of at least the intermediate and deep focus earthquakes. Phase discontinuties within the mantle, and even at the mantle-crust interface/transition may be tentatively visualised as zones of such spontaneous release of energy.

The behaviour of a complex system can only be predicted on the basis of a dynamic theory, since the present state and past history are not completely known Similarly in the case of earthquake prediction it is absolutely necessary to have some quantitative knowledge on the stress state of the earth. Since no such methods exist there is no likelihood of any advance in the solution of the problem of earthquake prediction in the near future. However, the study of earthquake time series provides another alternative approach. Probability of return of large events can be calculated by standard methods, Here the advantage is in the basic assumption of stationarity in time. Time spans of the order of history of mankind are more than three orders of magnitude smaller than the thermal time constant of the earth's crust. No appreciable changes in the earthe's thermal field is likely in such an interval.

The Deccan lava flows and the Panvel flexure close to the west coast are interesting from another standpoint. The five major crustal flexures/downwarps are related to extrusions of thick sequences of flood basalts, namely (1) the Panvel flexure and Deccan Traps, (2) the Lebombo flexure and the Karroo lavas, Africa, (3) the East Greenland flexure and the associated basic dyke swarms and overlying lava flows, (4) Snake River Basalts and the western Snake River plain graben and warp; Columbia River Basalts and the fissures in the southern and eastern Columbia plateau, N. America and (5) the Red Sea volcanics, the Shugra Vo'canic field and the Red Sea graben and Gulf of Aden flexure. As pointed out by Gibson (1966) it is intriguing that in most of the cases dyke swarms are associated with the flexures or warps. There are evidences at places to show that the dykes and flexures were Contemporaneous with the lavas. Gibson adds that gererally tension prevailed at the time of developments of faults and flexures.

It is also significant that in Greenland and Western India the flexures/warps are marginal to the continents and tend to parallel some mid-oceanic ridge. The Red Sea rift and the warp/monocline on the north of Gulf of Aden seem to be directly related to the Carlsberg Ridge. Such ridges or rifts have often been considered to be avenues of repeated basalt floods, some of which might have extented to the continental margin weighing it down to a warp. Marginal faulting may be an outcome of this phenomenon.

The purpose of the above discussion of processes and events of relevance to the Koyna earthquake and the Deccan basaltic lavas is to indicate the complex nature of the processes which might have caused the Koyna earthquake.

There is of late an increasing consciousness about the possibilities of earthquake prediction. Such a possibility, if based on mechanical determinations alone, can provide a novel solution of problems and safety from hazards. Those who are uninitiated may feel highly optimistic about it, and may go ahead to regret the lack of foresight on the part of many a responsible person. It would probably shock many if it is said that the Koyna event was one of those unpredictable probabilities.

A few highly affluent nations are contemplating on initiating systematic studies with a view to earthquake prediction. In these countries such planning is bassed on systematic earthquake observations spread over the past 40 years. The huge quantity of information available enabled these nations to plan the programme of earthquake-prediction research. Scientists of Japan are on the thershold of such an endeavour which would run for 5 years. From such studies they hope to obtain only clues for actual prediction Earthquake-prediction research entails (1) observations in tide-gauge stations, (2) geodetic observations, (4) continuous observation of crustal deformation by tiltmeters (horizontal, pendulum and water-tube types) and extensometers (invar-wire and silica-tube types), (4) observations on all earthquakes including the micro and ultra-micro earthquakes with the help of high magnification seismometers and ultra-sensitive seismometers with electronic amplifiers, (5) observations on variations in seismic wave velocities by explosion seismology, (6) studies on active faults and folding, (7) experiments on rock breaking and studies in geothermy, (8) magnetometric surveys, (9) precise observations of secular variations by proton-precision magnetometers, (10) differential proton-precision magnetometer studies and (11) studies on conductivity anomalies in the crust and mantle Such operations over a period of 5 years are going to cost 9.5 million U. S. dollar (71 million rupees) to the Japanese Government. Japanese scientists are not sure whether earthquake, prediction would be possible after this resarch programme is over. They foresee another similar period of study before feasibility assessment is possible.

For India the cost of such studies may be four times as much provided the technical know-how is readily available.

The above estimates may be an eye-opener for those who migth feel rather enthusiastic about earthquake prediction. At the same time the foregoing discussions may convince those who seem to demand the impossible from the earth-scientist.

Nevertheless, even the minimum probably has not been done. There is hardly any further scope for theoratical speculations, unless somebody is intent upon inviting embarrassment. The information on Koyna possibly has not provided adequate clues as to the cause of the earthquake. The principal avenues of exploration would be revealed by the interpretations of the seismological information and further seismology including studies on guided waves, geodetic surveys, geophysical investigations on the first and second order discontinuities and geothermal studies.

It needs to be emphasised that the stability of the Deccan Trap country particularly near the western coast, is a conjecture subjected to verification. Suspicions on stability are speculations too. These lava flows have blanketed a region of varied tectonic characteristics. Rational extention of surface information may not be rewarding. The problem involves deeper layers of the crust and perhaps the mantle. Future investigations may have to probe into these. These studies are intricate and indirect, and hence, qualitative and even speculative. Spectacular and smashing results may be hard to obtain. These would restrain the earth-scientist to apparent failures. The present generation may kindly tolerate them.

INAUGURAL ADDRESS

Dr. K. L. Rao,
Union Minister for Irrigation and Power

Mr. President and Friends,

Earthquakes are quite common in occurrence and humanity has to be prepared to face these for many million years till the internal structure of the earth becomes stabilized. We should not forget the fact that earthquakes occur quite in large numbers every year. There are a million shocks a year but fortunately only a few of them are disastrous. Nevertheless, since the beginning of this century earthquakes have, on an average, killed over 15,000 persons annually and caused thousands of millions of rupees worth of damage each year. Some countries such as China and Japan, Chile and Peru, Italy, Greece, Turkey and Iran have suffered far more heavily than others. In India severe earthquakes seem to occur at intervals of 10 to 20 years.

In a sense, there is not much one can do about earthquakes; there is certainly no means of stopping them. However, a lot is being done to make them less dangerous. Although we are still far from being able to forecast when earthquakes will occur, the patient accumulation of observations is making it possible to define more accurately the zones where the danger exists. All over the world, more so within these danger zones, scientists are active to find out the reasons for the occurrence of earthquakes and to design structures to make life less unsafe against damages resulting from earthquakes. This research requires a co-ordinated effort of scientists of different disciplines. This work and knowledge obtained therefrom, is extremely useful. It may even in some cases determine the choice of site for a dam, a power station, a factory or a new town. More often, however, other factors have over-riding importance and building must go ahead in certain places regardless of the earthquake danger. This is where earthquake engineering specialists have to scratch their brains, to prepare appropriate designs that will make the structures earthquake-resistant or earthquake proof.

In India we have been making scientific studies but our studies are not continuous. When an earthquake occurs, we get active like after shocks but after that soon we forget till another shock occurs. We should be sustained in our research. This should be the chief resolution that we should adopt at this Earthquake Seminar.

The Koyna Earthquake is very very distinct. It has occurred at a place where geologists suspected the least. It has occurred in intensity which was not thought of. Its after shocks persisted quite appreciably and all after shocks were traced to the Koyna region. We are building engineering structures in this region and therefore the subject has become doubly important both for the safety of the people as also for the safety of these costly structures.

As you are aware, in view of the magnitude and the peculiar nature of the problem, an International Committee was appointed through the aegis of the UNESCO. The Committee consisted of experts from England, France, USSR and Japan and India. They made very valuable studies and have submitted their final report recently. This report is under study.

One important lesson of the recent enquiry is that we should always gather histrorical information which may throw some light. Information obtained for this western region of the peninsular shield indicates the existence of seismic activity in the previous centuries. It is said that during the last four centuries, some 30 earthquakes of varying magnitude have been recorded in this region of the Indian Peninsula. One of these reported to have occurred 200 years back, if the reports are to be believed, seems to have been of about the same magnitude as the December 1967 shock. The rest seem to have been comparatively much smaller ones. These seem to include also the sizable aftershocks of the main shocks.

No special tectonic investigations having been carried out in the area, there is, therefore, no data available. Geologists seem to be of the opinion that there is no evidence of any major fault in Basalt rock in this area to which the origin of the earthquake can be ascribed. However, taking into consideration the fact that a number of shocks, most of them minor and some of them larger have occurred recently in the Koyna region, one feels curious. It seems that while there may be no evidence of fault in the top covering of trap rock itself, there is perhaps some seismogenic fault lower down in the basement rock, responsible for these shoks.

Naturally various theories have been put forward as the probable causes of these earthquakes. One opinion relates the major shocks as well as the number of smaller tremors experienced in the area in the last few years, to the formation of the Koyna Lake. Some say that the presence of the thirty odd hot springs that exist along the western slope of the western ghats between Bombay and Kolhapur and the reported increase in temperature of the water after the shocks is another significient factor. Another school seems to relate these shocks to possible underground nuclear testing in the antipodal area. Yet another opinion is that these shocks, including all the earlier tremors are tectonic in origin, the earlier significant shocks being merely the fore-shocks for the lage December earthquake. Some seem to suggest that the shocks may be of an indication of volcanic origin. The evidence in favour of everyone of these needs to be shifted and dispassionate attempts made to get at the real or the most probable contributing cause The UNESCO Study-Team went into all these theories and came to the conclusion that the (Koyna) reservoir was not responsible for the two major shoks of September and December, 1967 and the earthquake was due to tectonic movement in the basement rock underlying the traps.

One good feature even in this grim picture was the availability of records from instruments installed in the Koyna Dam and in its vicinity. It is very rare that an earthquake shock of such a large magnitude occurs so near an important structure as in the Koyna Project and rarer still that instrumental records indicating the behaviour of such structures under the shock became available. The Koyna Earthquake of December 1967 is unique in this respect ; I am sure the results of the engineering studies of the behaviour of structures will also be discussed some time soon.

So long as people suffer from earthqukes, education and research, studies and experiments in seismology and earthquake engineering must continue with utmost speed. There are now over 400 observatories installed in different parts of the world. This network of soismological observatories must be improved and the accurate mapping of earthquake danger zones should be extended to cover the entire earth. Design and construction of all the structures must be adequately ensured, against dangers of earthquakes. Young scientists and engineers should be trained to specialise in these new subjects.

In India, we have a special responsibility to pay more attention to the study of earthquakes as a large part of the country, specially in the Himalayan region is subject to occurrence of earthquakes. In particular we lack coordination and the main object of this symposium must be to provide this common forum for the scientists of different departments, Universities etc. to discuss and evolve safe and economic measures to overcome the effects of earthquakes.

I wish to thank Mr. Balasundaram and other friends, who have organised this useful seminar. I wish complete success for your deliberations.

ABSTRACTS OF PAPERS

Geology and Tectonics

SOME ASPECT OF KOYNA EARTHQUAKE OF 11th DECEMBER 1967, G. C. Chaterji and M. S. Balasundaram, Gelogical Survey of India.

With the construction of 96.6 m high Koyna dam and the filling up of the Shivajisagar in 1961–62, minor tremors were felt in the Koyna area. Their intensity (not more than IV MM scale) and frequency increased from 1965 ultimately culminating in two major shocks on 13th September and 11th December, 1967 with intensities of VII and VIII respectively. The occurrence of the major shocks in this part of the Deccan Plateau has aroused considerable controversy in regard to the assumed aseismic nature of the Peninsulan shield. A few are of the opinion that the tremors may be due to the reservoir loading.

Briefly the problems posed are as follows :—

1. Are the minor and major tremors due to one and the same cause.
2. Did the reservoir loading trigger the tremors and is it in any way connected with the major earthquakes of September and December, 1967.
3. The damage caused is limited to an area within a radius of 30 km even though the felt area is over a radius of 700 km. Is there any explanation for this restricted area of damage ?
4. Is it tectonic or volcanic in origin.
5. Has the Peninsular shield become unstable or is it only the narrow belt parallel to the coast seismically active ?

The authors in their brief paper have discussed some aspect of the problems but feel that more definite opinion could be expresssed only when the Deccan Volcanism in all aspects viz. geological, geomorphological, geophysical, have been studied, FUTURE STUDIES OF DECCAN TRAPS, A. P. Subramaniam, Geological Survey of India.

The Deccan trap formation composed largely of flows of Tholeiitic basalt with a few eruptive and plutonic centres along lines of tectonic weakness, constitutes one of the most important geological units of this sub-continent. It is also perhaps the least studied lava province in the world. Considering the aerial extent of the formation occupying as it does over 5,00,000 sq. km in parts of western and central India, the geological knowledge on the various aspects of this formation is still meagre It is, therefore suggested that every attempt should be made in the next few years on the following lines in order to understand the tectonic and other features of the lava units and the configuration of the pre-volcanic surface.

1. Photogeological studies to decipher the main geomorphological features, tectonic elements such as shear and shatter zones, dyke patterns and centres of eruption.
2. Ground check up and mapping on the scale 1:63, 360 in order to establish the lava stratigraphy to decipher the fabrics and sequence of flows in different areas to help in their correlation. Study of thermal springs in lava country to determine their tectonic setting.
3. Detailed measurements of sections of lava flows along ghat sections for rock colletions in specific columns ; these will be subject to petrographic, mineralogical geochemical and geochronological studies.
4. Critical geological mapping of specific areas, more particularly dyke swarms and eruptive centres followed by detailed petrographic, geochemical and geochronological studies.
5. Detailed study of the Deccan trap inter-face with the older pre-volcanic surface.
6. Geophysical studies on a regional basis to establish the depth of the pre-volcanic surface and the geomagnetic properties of the rocks
7. Putting down some drill holes in critical areas for collection of rocks from lava units at depths in order to decipher differentiation trends in various cooling units.

The above comprehensive programme of study of the Deccan basalt spread over the next 20 to 25 years will contribute to our fuller understanding of the generation and mechanism of the emplacement of basaltic magma and the history of the Certaceo-Eocene volcanism in India including the seismicity of the Deccan Volcanics.

SOME ASPECTS OF THE TECTONICS OF WESTERN MAHARASHTRA, A P Subramaniam and Y. S Sahasrabudhe, Geological Survey of India.

The recent Koynanagar earthquake has awakened interest on the tectonics of western Maharashtra. The major tectonic features of this part of the stable shield have been obscured by the thick pile of lavas extruded during the Cretaceo-Eocene times over a period of nearly 50 million years. The undulatory unconformable contacts of the lavas with the underlying prevolcanic formations and absence of any evidence of trough faulting in the river valleys suggest that lavas generally occupied erosional valleys. The almost straight margin of the Western Coast trending NNW-SSE as well as the roughly parallel continental divide, the almost similar trend of the major fault inferred along the continental shelf, the N-S line of thermal springs of the Konkan and the Panvel flexure are some of the major tectonic features. Furthermore there are many shear zones and shatter zones in the lava flows with trend varying from NNW-SSE TO NNE-SSW. All these tectonic features are suggestive of the continental margin having been a zone of crustal disturbance. This is also confirmed by the several earthquakes in Western Maharashtra recorded in the historical past.

There have been also several vertical movements along the Western coast and the Western ghats during the late Tertiary period. Among these are the postulated West coast fault, the uplift and tilt of the Charnockite massifs of southern India, the uplift of parts of the West coast as in Kerala and Saurashtra and submergence of the Bombay dockyard area in recent times.

The elliptical trends of the isoseismals of the recent earthquake with their longer axis roughly aligned N–S, the general trend of the ground fissures produced by the earthquake, and the alignment of the epicentres of Koyna earthquake tremors over the last four years follow a trend nearly paralleling the major lines of weakness viz. N–S.

GEOLOGY OF THE KOYNA VALLEY, Y. S. Sahasrabudhe, V. V. Rane, S.S. Desmukh, Geological Survey of India.

The paper embodies the results of critical study of the Deccan lava flows in the Kumbharli ghat section (Karad-Chiplum road, 6 kms west of the dam) between Rls 450 and 2391 feet and geological mapping of the flows on the photostat enlargement on scale 1 : 15,840 of the Koyna river valley, up and down stream of the dam, between the reservoir level and 2750 feet elevation. In the Kumbharli ghat section as many as 23 flows have been demarcated within a vertical column of about 2000 feet. maximum and minimum thickness of the individual flows varying between 270 and 25 feet, respectively In the Koyna valley area 8 flows have been mapped between Rls 1950 and 2750 feet, the maximum and minimum thickness of the flows being 200 and 50 feet, respectively. Massive and vesicular are the two broad lithological varieties in the flows and they show undulatory contact There are no intertrappean beds and lava flows are devoid of dykes. The vesicular amygdular flows at places are agglomeratic, brecciated tuffaceous and simulate the pyroclastic effusive rocks Red bole beds separating the different flows have been encountered at elevations of 425, 500, 650, 1225, 2200, 2350, 2475 and 2700 feet. X-ray diffraction studies on the tuffaceous rocks below the reservoir level but from the Kumbharli ghat section has revealed the presence of montmorillonite as major clay mineral with traces of illite at place.

The flows show a gentle dip of 1 or 2 degrees towards west and are traversed by vertical joints predominantly in N–S and E–W directions. They have been traversed by several shatter zones or shears which generally trend roughly N–S and are traced over a length of 6000 feet with a vertical extension of about 900 feet. These shears and joint patterns are responsible for the en-echelon displacemet pattern of the hill trends forming the continental divide and similar changes in the Koyna river course. The study has not revealed any conspicuous fault along the Koyna river valley.

INTERPRETATION OF AERIAL PHOTOGRAPHS OF KOYNA REGION B. G. Deshpande and P. N. Jagtap, Oil and Natural Gas Commission, Dehradun.

The paper embodies the results of a comparative study of two sets of aerial photographs of the Koyna Project area taken in 1950 and after the earthquake, in 1968, with special reference to physiographic and structural features of the Deccan lava flows occupying the entire area under consideration. Due to different scales of the two sets of photographs taken along different strips, many of the features could not be compared. However, presence of lineaments mostly oriented in N-S and NNW–SSE direction and in conformity with the apparent N-S course of the Koyna north of the dam together with bends and straights are of significance. The comparison does not bring out (i) any change in the trends of the lineaments, (ii) loosening of cliffs, (iii) major landslides or (iv) visible changes in the stream courses. A number of circular dark patches sloping radially outwards with a central white toned area simulating volcanic vents are actually dry ponds which are restricted to the topmost flow only. Ground work will be necessary to check whether they are of tectonic origin. Detailed photogeological studies of the area are recommended

A NOTE ON THE GEOLOGICAL AND PHOTO GEOMORPHOLOGICAL OBSERVATIONS OF THE KOYNA EARTHQUAKE AFFECTED REGION, MAHARASHTRA
S. A. Marawar and P. N. Jagtap, Directorate of Geology and Mines, Nagpur.

The N–S oriented cracks developed due to the severe earthquake of 11th December 1967 and the NNW–SSE oriented fractures and lineaments as found out from the air-photo study are discussed in the context of the existing structural data and it is felt that northward movement of Indian Peninsular shield along the Laccadive Chagos alignment which passes very near to the western coast between Goa and Bombay is the cause of the frequent earthquakes along the western coast. It is also concluded that the western coast of Maharashtra falls in the active zone of seismicity but due to the thick cover of the hard Deccan trap rocks shocks fail to reach the surface with the severe intensity and hence this region can still be called immune to earthquakes.

SOME ASPECT OF THE SEISMICITY OF THE PININSULAR SHIELD, C. Karunakaran and T.M. Mahadevan, Geological Survey of India.

The recent Koyna earthquake has set geoscientists rethinking on the susceptibility of the Peninsular Shield to intense seismic disturbances. Numerous tremors have been experienced in the past mostly in part of the Shield nearer the East and West Coasts, some of which have touched intensities of VI M.M In contrast to the earthquake in the non-orogenic terrains such as these experienced in the non-orogenic regions such as the Peninsular Shield are little understood, because of the contrasting geological setting obtaining in these regions. An attempt is made in this paper to analyse the various geological factors which have a bearing on the seismicity of the shield and to suggest lines of future studies which would help in the understanding of the earthquakes in the Peninsular Shield. Such studies should include (i) detailed gravity and seismic studies in select areas with a view to determining the structure and configuration of the crust and (ii) an intergrated programme of seismological studies in select regions in the Peninsular Shield to pre-determine the characteristics of future tremors.

THE KOYNA EARTHQUAKE AND IGNEOUS ACTIVITY, L. V. Agashe, Chairman, Board of Technical Examinations, Maharashtra State, and R. B. Gupte, College of Engineering, Poona.

The Koyna earthquake of 11th December, 1967 is considered to be of tectonic origin. However, in view of the absence of any evidence of tectonic movements this explanation seems inadequate, and it is suggested that this earthquake might have been caused by deep seated magmatic activity.

Some basalt flows in the Daccan Trap region seem to be later to the establishment of the existing drainage pattern. Such recent flows and the hot springs indicate recent volcanic activity in the region. It is on record that the temperatures of the hot springs rose significantly after the earthquake suggesting a close relationship between it and magmatic activity. The steep geothermal gradients in the Cambay and Ankleshwar wells of the O.N G.C. and the super heated stream reported to have been met with in some wells also indicate the proximity of igneous magmas. There is thus much evidence to suggest that the deep seated magma movements may have been responsible for the earthquake.

TECTONICS OF THE DECCAN PLATEAU AND KOYNA EARTHQUAKE, V.D. Muthayya and S.P. Subramanian, Indian Institute of Technology, Madras.

The severe earthquake that occurred in Koynanagar area on the 11th December, 1967 is described to be something strange and quite new in the Deccan region which is considered to be stable and not subjected to violent earthquakes in the past In this paper an attempt is made to probe into the causes for this earthquake with particular reference to its possible relation to the tectonics of the Deccan plateau. A summary of the stratigraphy and tectonics of the Peninsular India is given together with the various views held by Seismologists, Geologists and Geoscientists in this context. In conclusion it is emphasized that the rejuvenation of faults and shear planes by neotectonic movements has rendered this region seismically active and therefore, the possibility of future earth tremors cannot altogether be ruled out. In view of this, necessary modification of the seismic zones of India and the installation of research stations to study neotectonic movements are suggested.

POST MESOZOIC TECTONIC ACTIVITIES IN THE WESTERN PART OF INDIAN PENINSULA AND THEIR EFFECTS ON THE DECCAN TRAPS, B.N. Niyogi and S.R. Pradhan, Geological Survey of India.

Following the effusion of the Deccan traps in the late Mesozoic-early Tertiary period, the Indian Peninsula has been affected by major tectonic disturbances although their character and intensity were relatively less spectacular than those in the Extra-Peninsula region. Nevertheless the tectonic events ushered insignificant changes in the Mesozoic continental configuration in this part of the globe Unlike the mobile belt of the Himalaya, the Indian Peninsula for a greater part of its area has highly elastic crystaline rocks and their response to the tectonic forces have been quite different from those in the Himalayan zone.

The tectonic events from Eocene to the present day have been brieflv described in this paper and their effects on the rocks particularly in the western part of the Peninsula (Maharashtra) have been indicated. Evidence of Tertiary and post-Tertiary tectonic movements in this area have been presented. The geomorphic evolution of the area has primarily been controlled by the tectonic events and the analyses of the former led to the clues to the understanding of the past tectonic events.

Significance of thermal springs occurring in the area on linear zones has been outlined.

Seismicity of the area in relation to the tectonic history has been discussed.

SAFETY PROBLEMS FOR DAMS WITH RELATION TO EARTHQUAKES, AND WITH PARTICULAR REFERENCE TO KOYNA EARTHQUAKE (11 DECEMBER 1967), S. S. Misra, Oil and Natural Gas Commission, Dehradun.

The Koyna dam site lies in the Deccan Trap area of the Peninsular India where earthquake of high intensity were unknown earlier and was also considered to be a stable region. At the dam the trap rocks comprise the basalt, tuff, flow breccias and ash beds and the red bole. The Geological Survey of India had carried out detailed study of the geological conditions at the dam site. The theory of under ground thermonuclear blast, as a cause of this earthquake, and the role of the continental theory in the present earthquake has been discounted. The author feels that the reasons are mainly of the tectonic nature. The additional load of impounded water, disintegration of red bole removing the support below the basaltic layers, role of geothermal gradients and possibility of unstable conditions of the western coast or in the shelf area on the western coast migth be the other reasons responsible for the Koyna earthquake.

EARTH TREMORS OF 1963 AROUND KOZHIKODE, KERALA STATE AND THEIR BEARING ON THE SEISMIC STABILITY OF THE WEST COAST, T.M. Mahadevan, Geological Survey of India.

Numerous seismic shocks of relatively low intensity are being felt in different parts of the Peninsular shield from time to time. An understanding of the geological causes of such tremors would help in the final evaluation of the seismic stability of the shield itself and in understanding earthquakes like those affecting the Koyna Region. This paper presents an account of a series of earth tremors that were experienced in the neighbourhood of Kozhikode between the 24th September and 4th October, 1961. A maximum intensity of IV MM was associated with one of these tremors which occurred at 1.25 P.M. on 26-9-1961. The earth tremors were felt over a stretch of the coast 20 km long with Kozhikode in the centre and upto about 32 km east of Kozhikode. The intensity waned towards the interior from the Kozikode coast. On an analysis of the various factors related to the earth tremors, it is concluded that they were the result of possible movements along weak planes or faults in the off shore region near Kozhikode resulting from minor crustal adjustments. The bearing of these conclusions on the problems posed by the earthquakes in Koyna is discussed.

A NOTE ON THE SUBTERRANEAN SOUND AND EARTH TREMORS IN HALBARGA VILLAGE, BHALKI TALUK, BIDAR DISTRICT, MYSORE, D. S. Deshmukh, Geological Survey of India.

Loud subterranean sounds and rumblings with feeble earth tremors were experienced around village Halbarga (18°00′ : 77°20′) 27 km from Bidar, Bhalki taluk, Bidar District, Mysore state between the 10th October and the 6th Novemb r, 1956. There was no damage to life or property. The tremors were very feeble and were felt in a very small area and not recorded even by the seismograph of the Indian Meteorological Observatory at Hyderabad. The intensity of the tremors appears to be between III and IV MM.

Halbarga rests on hard, massive, dense dark grey Deccan traps with a thick cover of black cotton soil. Though the area is generally believed to be aseismic, many feeble earth tremors accompanied by rumbling sounds are recorded in this part of the shield during historic times.

The tremors are possibly due to development of some minor dislocations and fractures in the trap below the mantle of soil and perhaps originated from shallow depths. The bearing of these observations on the seismic susceptibility of the Deccan Trap region in general is discussed.

A NOTE ON GEOLOGIC AND SEISMO-TECTONIC SETTING OF PENINSULAR INDIA WITH SPECIAL RFFFERENCE TO THE EARTHQUAKES IN MAHA-RASHTRA, L. S. Srivastava and R S. Tipnis, School of Reserch and Training in Earthquake Engineering, University of Roorkee, Roorkee.

A large part of the Peninsular Shield was strongly shaken by a severe earthquake on December 11, 1967 with its epicentre near Koynanagar. This earthquake caused great damage resulting in considerable loss of life and property in the region. Due to lack of instrumental data, sporadic minor earthquake activity and the shield character of the Peninsula, this part of Deccan was generally considered aseismic. Contrary to this belief, a careful study of all the past historical records will reveal that there were many occurrences of earthquakes in the western coast of Maharashtra showing that the area was seismologically active.

This paper describes in brief the geology and seismo-tectonics of the Peninsular Shield. Special reference is made to the earthquake activity in Maharashtra and various theories regarding the origin of the earthquakes have also been discussed.

ENGINEERING

KOYNA EARTHQUAKE AND ITS EFFECT ON THE KOYNA HYDRO ELECTRIC PROJECT, M. S. Balasundaram and P. B. Srinivasan, Geological Survey of India.

This paper describes in brief the geological setting of the Koyna Project area and the effect of the Koyna earthquakes of 13th September and 11th December, 1967 on the project features. The 96.6 m. high Koyna dam, tunnels and power house are all located in Deccan Trap formation consisting of massive and amygdaloidal varieties. The latter is also agglomeratic and brecciated at places and are separated by 'red bole' beds. They are horizontally disposed with occasional gentle flexures at the contacts of flows. The Koyna dam in monoliths 1–14 and 24–38 is founded on a massive flow between KRLs 1880 and 2000. In the river bed, the foundation was taken down to KRL 1840 in order to reach the lower massive basalt. In the dam a significant shear zone trending N–S traversing monoliths 12 to 14 and other shear zones in the tail race and head race tunnels were delineated and treated. No fault was noticed at the dam site and in the valley now forming the lake. Recent work has also not indicated any fault in the Kumbharli ghat section near Koyna.

During the construction stage no tremors were experienced in Koyna. But from 1963 onwards soon after the reservoir filled up minor tremors started. These increased in frequency and intensity from 1965 onwards ; the intensity being never more than IV M M. scale and an average magnitude of 2.5 Richter scale (maximum 3.75). This was believed to be triggered by the reservoir loading as was the case in Lake Mead reservoir (U S A.). Surprisingly on the 13th September and 11th Dec mber, 1967 two major shocks shook the Koynanagar, the latter particuarly destroying the whole of Koynanagar and badly shaking the dam itself resulting in the development of several cracks both horizontal and vertical and consequent increased leakage. Comparatively there was little damage to the underground power house and the appurtenant structures.

In the Koyna dam an acceleration of 0.05 of horizontal was provided. During the September and December quakes the accelerations are said to be 0.15 and 0.40 (horizontal), respectively. Even though the epicentres are said to be close to the dam, it stood the shocks well but was shaken badly resulting in the development of cracks. This dam structure requires both immediate as well as long term stabilization against future earthquake in the area. In conclusion the paper also stressess the further regional studies required in the Deccan plateau particularly the area between the Western Ghats and the coast of Maharashtra State.

HYDRODYNAMIC EFFECTS OF IMPOUNDING WATER UPON VIBRATION OF A DAM, Y.C. Das, A.V. Setlur, and G.V. Berg, Indian Institute of Technology, Kanpur.

The frequencies and mode shapes of a dam play a major role in detremining the response of a dam subjected to an earthquake. Upto the presnt time this hydrodynamic effects of the impounding water on the natural frequencies of a dam have not been treated on a dynamic basis. Here, the dam and the impounding water are treated as composite system interacting one against the other when the system is subjected to vibration. An analytical method is developed to obtain the frequencies, mode shapes and the hydrodynamic pressure distributions when the system is subjected to free vibrations. It is found that pressure distribution is dependant on the mode of vibration of the dam. The modes of the composite system are shown to be orthogonal to one another.

The response of a dam subjected to ground acceleration is obtained in a modal series and the resulting pressure on the dam is also obtained in a series of the modal pressure.

This analysis is applied to the dynamic respone of the Koyna Dam subjected to the December 11th, 1967 earthquake.

STUDY OF DAMAGES AND THROWS IN KOYNA EARTHQUAKE, R. N. Joshi, Chartered Engineer, Bombay.

The paper reports the observations of damages to structures during the Koyna earthquake. The zone of heavy damage appears to be an elliptical area. Most of the building structures in the area are ground floored ones built in masonry. They are mostly in ruins. Study of cracks and failures of structures indicates several specific types which have been broadly analysed and presented. Likely seismic acceleration has been worked out in some cases. Directionwise study of the throws of free objects has been made to draw inferences therefrom regarding the shaking during the earthquake. A scrutiny has been made to find out if the structural failures indicate any similarity by directions and if this one fits in with the throws of free objects. Pictures have been given to indicated the observations made. Desirability of upgrading of seismic zones in the Deccan has been discussed. The necessity of educating the public in adopting the basic principles of earthquake resistant structures is emphasised as it is felt that any possibility of recurrence of earthquakes in the Peninsular region should be taken with alertness and caution rather than with panic. It is also necessary to take a nationwide review of materials to be used extensively for earthquake resistant construction.

CONSTRUCTION OF SMALL BUILDINGS IN SEISMIC AREAS, A. S. Arya, School of of Reserch and Training in Earthquake Engineering, University of Roorkee, Roorkee.

The general principles of earthquake resistant construction as evidenced by studies of damage in various past earthquakes are first described. Then recommendations are given for constructing buildings in masonry and timber or tubular framework. Finally a few designs of small houses are presented which could be adopted for construction of houses in a seismic area.

GEOPHYSICS AND SEISMOLOGY

A PLEA FOR SYSTEMATIC EARTHQUAKE STUDIES IN INDIA, P.C. Hazra, Geological Survey of India.

The need for systematic earthquake studies in India has been felt for some time past. Catastrophic events like the recent Koyna earthqake focus our attention to this necessity more acutely. Such studies are to be conducted from a network of stations scattered all over the country. The locations of these stations should be based on the knowledge regarding the seismicity of the different tectonic blocks, status of faults and folds, evidences of Quaternary tectonism and the interpretations of geodetic data. In such an integrated programme of study, seismologists and geologists as well as civil engineers have important roles to play. The locations of 80 top-priority observation stations have been indicated on the basis of a brief analysis of the available information. Earthscientists are urged to make all out efforts for an early implementation of a programme of systematic earthquake studies in the country so that we may be better prepared for the future.

THE KOYNA EARTHQUAKE OF 11-12-67 AND THE DAMAGE CAUSED BY IT,

M. S. Jain, G. S. Ghodke and N.G. Gajbhiye, Geological Survey of India.

The earthquake which shook the 96.6 m high rubble concrete Koyna dam at 4.21 hrs. on 11-12-67 had been felt over a radius of 700 km. To assess the extent, nature and type of damage about 200 villages spread over an area of 800 sq. km. were visited and data collected. The dam and its immediate vicinity exhibit damage pattern symptomatic of intensity VIII on the M. M. scale as adopted by ISI (code No. 15 : 1892-1966) Most of the *Pucca* and semi-*pucca* houses within a radius of 10 km of the dam have been destroyed. The reinforced concrete building have, however, withstood the shocks without damage. It is also to be pointed out that the electric and telephone posts as well as pipelines and plumbings have all remained virtually unaffected though the roofs of the houses have all collapsed.

The shape of the various isoseists (VIII to VI) is that of a broad ellipse with the long axis trending roughly N-S. The damage spectrum of the higher isoseismals is broader towards the east and is narrower towards the west. Some of the stone pedestals have shown movement both in the clock wise and anticlock wise directions. The nature and extent of damages exhibited in the area of the Veena, Krishna and Kudal valleys are rather on the higher side even though within isoseist-V. This, however, gets reconciled when the damage is viewed in the light of the local geology.

The Kadoli-Donachiwadi fissure has a N 10°W to N 25°E trend but it is confined mostly to the soil capping. In addition the paper discusses the movement patterns of objects thrown out, various rock-falls and soil-cum-rock slips in the N-S to N 10°W-S 10°E.

The direction of motion as ascertained from enquiries has been mostly from N to S. In majority of cases, the N-S walls of building have tilted to west at roof level. The behaviour of Shivajisagar lake has been, however, very enigmatic. There has been no report of any wave motion due to this earthquake which originated only about 6 km south to the dam.

The type and the severity of the damage suggest that the focus is perhaps at shallow depth and as per isoseismals the epicentre tract may be near the Rohine-Kadoli group of villages, on the south bank of the Koyna river near Helwak.

GROUND MOVEMENT CHARACTERISTICS OF THE KOYNA EAKTHQUAKE,

A V. Setlur, Y.C. Das, K.V.G K. Gokhale and G V. Berg. Indian Institute of Technology, Kanpur.

Response spectra can play an important role in the aseismic design of structures, and the special characteristics of particular earthquakes are revealed by the response spectra and the ground movements. Computation of ground movements requires special precautions on the locations and adjustment of the base line of the accelerographs from which they are computed.

This paper presents response spectra and computed ground velocities and ground displacements for the earthquake recorded at Koyna on September 13 and December 11, 1967. The peculiarities of the spectra and the ground movements are interpreted in relation to the geology of the region and the location of the accelerograph in the Dam.

RECENT SERIES OF EARTHQUAKES IN THE KOYNANAGAR, A POSSIBLE SOURCE MECHANISM,

T.K Dutta, Regional Research Laboratory. Jorhat, Assam.

The occurrence of the recent earthquake shocks with a peak magnitude around 7 on

Richter scale, in Koynanager poses a number of problems It is difficult to trace this occurence to any measurable fault movement along a known fault. Besides the energy associated with this earthquake also precludes the possibilities of surface structural or load changes as a causative factor.

In this note an attempt has been made to outline a possible source mechanism for this event. On the basis of geological evidences regarding intense volcanic activities in the past, thermodynamically possible process, capable of releasing necessary energy, is put forward by applying principles of energy transfer during permissible phase transition in the crust and the mantle of the earth.

STRAIN CHARACTERISTICS OF SOUTH INDIA AND THE KOYNA EARTHQUAKE,
R.K.S. Chouhan, Benaras Hindu University and V.K. Gaur, University of Roorkee.

The strain accumulation and release curve for shallow earthquakes of south India and its neighbourhood has been constructed for 37 years, from 1930 to 1967 using Richer magnitude 4.7 and above. The curve shows that the rate of strain release is uniform throughout although the activity is not a continuous one being intercepted by quiescent periods. This curve clearly defines the position of the Koyna earthquake of December 11, 1967.

Accumulated strain rebound increments of the aftershocks of the Koyna Earthquake having unified magnitude 5 and above are shown diagramatically which show two segments of recovery one corresponding to the compressional creep recovery and other for shear creep recovery. The relaxation time for this sequence is about 14 days which corresponds to Kelvin body.

Frequency magnitude analysis of the microtremors shows that the microseismic activity can be defined by an equation of the form:

$$\mathrm{Log}_{10}^{N} = 4.65 + 0.87\ M$$

where N is the number of earthquake having magnitude M or greater.

RECENT SEISMIC DISTURBANCES IN THE SHIVAJISAGAR LAKE AREA OF THE KOYNA HYDROELECTRIC PROJECT, MAHARASHTRA, INDIA. S K. Guha, P.D. Gosavi, M.M. Verma, S.P. Agarwal, J G. Padale & S.C. Marwadi. C.W. & P.R.S., Poona.

Shivajisagar Lake area of the Koyna Hydroelectric Project was more or less free from any earth tremor before the impounding of the reservoir. But subsequent to the filling up of the reservoir in 1963, the reservoir area began to experience mild earth tremors whose frequency of occurrence and magnitude rose steadily to higher values. Until September 1967, the maximum magnitude of the earth tremors was about 3.75 in Richter scale. But on the 13th September 1967, a moderate earthquake of magnitude 5.7 occurred with epicentre very near the dam. The felt radius of this earthquake was about 120 km and the maximum intensity was about VII in the MM scale. This earthquake was followed unexpectedly by another major shock on the 11th December 1967; this time also the epicentre being very near the dam This earthquake had a magnitude of about 7.0 and the radius of felt area was of about 700 km. This can be rated as the largest earthquake ever to occur in historical time in the Peninsular Shield of India which is considered to be a stable landmass.

A SHORT NOTE ON GRAVITY AND SEISMIC INVESTIGATIONS IN THE KOYNA AREA, L.N. Kailasam, Geological Survey of India.

In order to investigate the structural features in the Koyna area and to determine, if possible, the thickness of the Deccan trap, one seismic and one gravity party were deputed for the investigation in the first week of January, 1968. The programme consisted of a few gravity traverses to the south of the Koyna dam across the Koyna river to investigate the possible occurrences of sheared or fault zone in this part of the area and one or two deep refraction shots in the Pophali valley west of the continental divide. In the light of the data obtained from the above investigation two additional regional gravity traverses were taken up along the Karad-Guhagar and Poladpur-Mahabaleshwar roads besides seismic soundings at Karad and Rampur.

The gravity profiles across the Koyna river to the south of the dam have yielded some interesting anomalies. The end portion and the terrain effects have to be corrected for. But the profiles appear to indicate a possible sheared zone in a north-south direction parallel to the river course. To determine the exact nature and the magnitude of the anomalies computation is now in progress.

The travel-time curves for seismic profiles indicate a possible discontinuity or interface at a depth of the 300 to 600 m from the ground surface in the area in general. But the exact base of the trap has to be determined by much longer profiles and this is not possible with the existing seismograph unless it is provided with a special communication. After suitably adopting the seismograph unit the work will be continued.

SEISMOMETRIC STUDY OF THE KOYNA EARTHQUAKE OF DECEMBER 11, 1867,

A.N. Tandon and H.M. Chandhury, India Meteorological Department, New Delhi.

The India Meteorological Department in its Seismological wing is responsible for the instrumental study of earthquakes and the Koyna Earthquake was, therefore, studied in some detail. The results are presented here.

The important parameters of an earthquake that permit instrumental study are (i) Location of the epicentre, Origin time and Depth of Focus (ii) its magnitude (iii) its mechanism and (iv) the aftershock activity.

The location of the epicentre and depth were done to satisfy all the available P-wave arrival times. We had about 150 readings from observatories outside the country extending to distance upto 15,000 km. From within we used our data as well as those from the very close range observatories operated by the C. W. and P. R. S. and the Array Station at Gauribidanur. In the complete absence of any knowledge about the structure of the crust in the area, we had to make a very large number of trials with plausible values of seismic wave velocities and on the basis of the best fit have accepted the following as the solution :

Epicentre	Lat.	17° 22'.4 N
	Long.	73° 44'.8 E
Origin times	22 : 51 : 19.0 GMT	
Depth	8 km	

This is about 4 km south of the Dam.

The magnitude was determind from the Standard Wood-Anderson seismograms and was found to be about 7½. But most of the observatories outside India reported lower magnitudes. In view of this we had to use the body waves from the standardised seismograms as well as the surface waves recorded at Port B air. These gave values of 6½ in agreement with the others. We have therefore accepted 6½ as the magnitude

The very shallow depth of 8 km and the magnitude of 6½ explains also the limited area of damage and the rapid fall of the intensities with distances. Yet the larger distance upto which the shock was felt i.e. about 700 km remain unexplained: It is possible that some sort of channel propogation of the wave energy may be responsible for this.

The mechanism of the earthquake was also studied by the Byerly's Method. We used more than 70 first motion and found out that they can be explained by faulting in a N 26 E direction, dipping 66° towards N 296° the motion being left handed and almost strike slip.

A number of stronger aftershocks recorded by our observatories were also located. They all trend in a NE–SW direction, the compratively deeper ones lying towards the western side of the zone. This lends support to the fault mechanism found above.

Bulletin of the Indian Society of Earthquake Technology Vol. 4, No. 4, pp. 37-41 December 1967

SEISMOLOGICAL NOTES

(India Meteorological Department, New Delhi)

Earthquakes in and near about India during July—December, 1967

Date 1967		Origin time (G.M.T.) h.	m.	s.	Epicentre Lat (°N)	Long (°E)	Region	Approx. depth (kms.)	Magnitude	Remarks
1		2	3	4	5	6	7	8	9	10
July	2	07	03	55 (SHL)	9.0	93.4	Nicobar Islands	—	6 2 (NDI)	—
		07	03	52.9 (CGS)	8.7	93.8	Nicobar Islands	33	5.7 (CGS)	—
July	2	08	32	38.5 (CGS)	33.2	75.6	Eastern Kashmir	33	4.8 (CGS)	Felt at Jullundhar and some other areas of Punjab.
July	2	14	09	37.6 (CGS)	8.5	93.8	Nicobar Islands	36	5.2 (CGS)	—
July	2	14	19	13.6 (CGS)	8.5	93.8	Nicobar Islands	33	4.9 (CGS)	—
July	2	18	36	18.9 (CGS)	8.6	93.8	—do—	33	4.5 (CGS)	—
July	7	22	56	30.8 (CGS)	27.8	92.2	India-China Border Region	33	4.9	—
July	7	23	49	23.6 (CGS)	35.5	87.8	Tibet	33	—	—
July	16	07	44	15 (SHL)	23.5	87.5	—	—	—	—
July	19	17	28	32.2 (CGS)	36.5	70.3	Hindukush Region	223	4.7 (CGS)	—
July	23	01	16	42.2 (CGS)	36.9	71.4	Afganistan USSR border	180	4.6 (CGS)	—
July	25	15	50	25 (NDI)	28.8	77.3	16 kms. N E of Delhi Observatory	—	—	Felt in Delhi.
July	28	17	27	33.7 (CGS)	2.1	98.0	Northern Sumatra	32	3.1 (CGS)	—
July	29	14	12	18.9 (CGS)	35.5	70 8	Hindukush Region	194	4.6 (CGS)	—
Aug.	4	08	06	59.1 (CGS)	34.8	70.1	Afganistan	33	4-8 (CGS)	—
Aug.	6	10	31	06.3 (CGS)	38.0	74.5	Tadzik Sink-iang Border	215	4.8 (CGS)	—

1	2	3	4	5	6	7	8	9	10
Aug. 7	05	49	57.5 (CGS)	36.5	71.2	Afganistan USSR Border	229	5.0	—
Aug. 11	01	57	05 (NDI)	16	80	Andhra Pradesh	—	—	—
Aug. 12	22	54	38.6	37.0	71.4	Afganistan USSR Border Region	121	5.1	—
Aug. 14	06	41	46.2	5.4	96.6	Northern Sumatra	33	5.2	—
Aug. 15	07	40	28.7 (CGL)	36.3	70.2	Hindukush Region	189	4.7 (CGS)	—
Aug. 15	09	21	02.3 (CGS)	31.1	93.7	Tibet	33	5.7 (CGS)	—
	09	21	00 (NDI)	31.0	93.5	Tibet	—	—	—
Aug. 16	19	18	57.6 (CGS)	0.9	98.9	Northern Sumatra	26	5.6 (CGS)	—
Aug. 19	01	34	43.5 (CGS)	36.9	71.5	Afganistan USSR Border Region	127	4.9 (CGS)	—
Aug. 20	17	19	35.0 (CGS)	37.1	95.7	Tsinghai (China)	33	4.5 (CGS)	—
Aug. 21	07	33	00.6 (CGS)	3.6	95.8	Off W. Coast of Northern Sumatra	33	5.9 (CGS)	—
	07	33	00 (NDI)	4.6	95.4	—	—	6.2 (NDI)	—
Aug. 22	07	32	57.0 (CGS)	5.8	96.2	Northern Sumatra	24	—	—
Aug. 24	01	17	09.6 (CGS)	35.3	88.0	Tibet	31	4.5 (CGS)	—
Aug. 27	04	49	59.7 (CGS)	36.3	71.1	Afganistan USSR Border Region	225	4.5 (CGS)	—
Aug. 27	11	11	57.2 (CGS)	23.1	94.2	Burma India Border Region	61	4.5 (CGS)	—
Aug. 28	21	05	51.7 (CGS)	36.5	80.1	Southern Sink-iang China	33	4.7 (CGS)	—
Sep. 6	01	43	31.8 (CGS)	24.1	91.7	India-East Pakistan Border Region	18	5.0 (CGS)	—
Sep. 6	07	30	10.8 (CGS)	14.7	93.6	Andaman Island Region	33	5.6 (CGS)	—
	07	30	10 (NDI)	14	94	—do—	—	—	

1		2	3	4	5	6	7	8	9	10
Sep.	8	00	26 (CGS)	02.5	36.9	71.5	Afganistan USSR Border Region	111	5.0 (CGS)	—
Sep.	8	05	23 (CGS)	40.5	38.4	70.5	Afganistan USSR Border Region	14	4.9 (CGS)	—
Sep.	11	06	12 (CGS)	00.5	27.5	66.4	W. Pakistan	36	4.6 (CGS)	—
Sep.	13	06	23 (NDI)	31	17.4	73.7	Near Koyna Dam in Maharashtra	4	5.8 (NDI)	Caused some damage in Koyna Nager and neighbourhood. Felt over a wide area upto Bombay. These earthquakes were preceeded and followed by a large number of smaller shocks.
Sep.	13	06	48 (NDI)	25	17.4	73.7	—do—	—	5.6 (NDI)	
Sep.	15	10	32 (CGS)	48.7	27.4	91.8	Bhutan	57	5.8 (CGS)	—
		10	32 (NDI)	46	27	92	Bhutan	—	6.0 (NDI)	—
Sep.	18	08	26 (CGS)	36.7	35.9	70.4	Hindukush Region	140	4.8 (CGS)	—
Sep.	20	20	25 (CGS)	05.8	32.6	76.1	Kashmir-H.P. Border Region	59	4.1 (NDI)	Felt at Jullundur.
Sep.	22	20	09 (CGS)	13.3	31.9	94.6	Tibet	33	—	—
Sep.	22	22	11 (CGS)	48.3	36.2	71.4	Afganistan USSR Border Region	127	4.7 (CGS)	—
Oct.	2	17	49 (CGS)	51.3	37.6	72.1	Tadzik SSR	105	4.3 (CGS)	—
Oct.	13	03	24 (CGS)	47.0	39.7	74.4	S. Sinkiang Province China	33	5.2 (CGS)	—
Oct.	18	00	55 (CGS)	07.3	23.4	94.9	Burma-India Border Region	54	4.8 (CGS)	—
Oct.	21	11	00 (CGS)	35.9	31.6	99.9	Szechwan Province, China	33	5.2 (CGS)	—
Nov.	3	16	40 (CGS)	48.6	39.8	77.5	S. Sinkiang Province, China	33	4.5 (CGS)	—
Nov.	7	19	57 (CGS)	26.1	37.0	71.7	Afganistan- USSR Border	136	5.3 (CGS)	—
		19	57 (SHL)	30	36.0	70.0	Hindukush	—	5.5 (NDI)	—

1	2	3	4	5	6	7	8	9	10
Nov. 10	06	04 (CGS)	09.4	25.5	91.7	India-East Pakistan Border	59	4.4 (CGS)	—
		—			—	—	—	5.5 (NDI)	—
Nov. 12	12	32 (CGS)	43.4	6.1	95.2	Nicobar Island	105	4.7 (CGS)	—
Nov. 14	00	04 (CGS)	17.8	24.0	91.5	India-East Pakistan Border	33	5.1 (CGS)	—
	00	04 (SHL)	34	26.0	91.0	Garo Hills	—	5.3 (NDI)	—
Nov. 16	00	41 (GCS)	24.7	37.6	69.7	Afganistan-USSR Border	33	4.7 (CGS)	—
Nov. 29	05	19 (GCS)	00.7	36.4	70.8	Hindukush	228	4.8 (CGS)	—
Dec. 4	21	41 (CGS)	50.9	2.8	65.1	Carlsberg Ridge	33	49 (CGS)	—
Dec. 9	04	56 (CGS	14.3	36.3	70.8	Hindukush	225	4.8 (CGS)	—
Dec. 10	18	43 (CGS)	34.4	22.5	94.8	Burma	158	5.2 (CGS)	—
Dec. 10	22	51 (CGS)	24.3	17.4	73.9	Koyna Nagar	33	6.0 (CGS)	Koyna Nagar Township razed to the ground. 177 people killed and 2300 injured. Felt over a large area in Peninsular India (A special note on this earthquake appears in the journal Vol. No. 4)
	22	51 (NDI)	19.0	17.37	73.74	3 kms South of Koyna Dam	8	7.5 (NDI)	NDI magnitude given are determined from Standard Wood Anderson seismograms from Indian Observatories
Dec. 10	23	52 (CGS)	16.7	17.4	73.7	Aftershock of Koyna Earthquake	33	5.0 (CGS)	—
Dec. 11	20	49 (CGS)	48.5	17.3	73.7	Aftershock of Koyna Main Earthquak	11	5.2 (CGS)	—
	20	49 (NDI)	47.5	17.27	73.68	—	—	5.8 (NDI)	—
Dec. 12	03	22 (CGS)	32.3	6.7	61.5	Carlsberg Ridge	33	—	—
Dec. 12	06	18 (CGS)	37.9	17.6	73.9	Aftershock of Koyna Earthquake	29	5.4 (CGS)	—
	06	18 (NDI)	33.5	17.29	73.65	—	—	6.2 (NDI)	—

1	2	3	4	5	6	7	8	9	10
Dec. 12	15	48 (CGS)	55.5	17.4	73.9	Aftershock of Koyna Earthquake	27	5.0 (CGS)	—
	15	48 (NDI)	51.7	17.29	73.63	—	—	5.9 (NDI)	—
Dec. 13	05	09 (NDI)	41.8	17.31	73.68	Aftershock of Koyna Earthquake	—	5.5 (NDI)	—
Dec. 13	19	19 (NDI)	45.5	17.50	73.62	Aftershock of Koyna Earthquake	—	5.6 (NDI)	—
Dec. 14	19	15 (CGS)	20.5	38.2	91.3	Tshinghai Province China	33	5.4 (CGS)	—
Dec. 17	00	25 (CGS)	15.1	36.5	71.4	Afganistan-USSR Border	82	5.2 (CGS)	—
Dec. 19	03	23 (CGS)	49.6	37.5	72.0	Tadzhik SSR	89	5.5 (CGS)	—
Dec. 20	11	34 (CGS)	25.9	11.8	93.0	Andaman Island	61	5.4 (CGS)	—
Dec. 21	23	43 (CGS)	11.4	11.8	93.1	Andaman Island	33	5.0 (CGS)	—
Dec. 24	23	49 (CGS)	53.9	17.5	73.9	Aftershock of Koyna Earthquake	33	5.5 (CGS)	—
	23	49 (NDI)	51	17.35	73.71	—	—	5.8 (NDI)	—
Dec. 25	17	37 (CGS)	39.1	17.2	73.9	Aftershock of Koyna Earthquake	33	5.1 (CGS)	—
Dec. 28	10	28 (NDI)	04.3	—	—	22 kms from Delhi	—	2.7 (NDI)	Felt at Delhi
Dec. 28	20	15 (CGS)	48.6	37.2	71.8	Afganistan-USSR Border	156	4.7 (CGS)	—
Dec. 29	06	24 (CGS)	50.3	36.3	70.2	Hindukush	230	4.7 (CGS)	—
Dec. 30	12	36 (CGS)	55.8	31.7	86.8	Tibet	24	4 9 (CGS)	—

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14–17 January 1969

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