Bulletin of the Indian Society of Earthquake Technology, Vol. 6, No. 4, pp. 157-165, Dec. 1969

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4th WORLD CONFERENCE IN EARTHQUAKE ENGINEERING

13-18, January, 1969, Santiago, Chile

The 4th World Conference on Earthquake Engineering which was held in Santiago, Chile, between January 13th and 18th, 1969, was attended by 380 participants from 29 countries. There were twelve technical sessions arranged under the following headings : Seismicity and Simulated Earthquakes ; Vibration Tests of Structures ; Ground Motion and Instruments ; Behaviour of Structural Elements ; Elastic Response of Structures ; Large Buildings and Structural Details ; Inelastic Seismic Response ; Design of Other Structures ; Soils and Soil Structures ; Foundations and Soil Structure Interaction ; Design Criteria and Research ; and Small Building Criteria and Research.

The following officers and Directors of the International Association of Earthquake Engineering were elected for the next four years. President : G. W. Housner, U. S. A: Executive Vice-President : R. Flores, Chile ; Secretary-General : J. K. Minami, Japan; Directors : O. A. Glogau, New Zealand, N. N. Ambraseys, Great Britain, A. Arias, Chile, F. J. Borges, Portugal, L E Esteva, Mexico, J. Krishna, India, S. Okamoto, Japan, S. Poliakov, U.S.S.R., and K. Steinbrugge, U.S.A.

The papers presented at the Conference indicated that a significant progress has been made in the study of Seismic Behaviour of Structures, Foundations and Effects of Earthquakes on Structures.

The following gives the titles of the 163 papers presented at the conference and the name of their authors. The proceedings of the Conference can be obtained from : The Executive Secretary, Organizing Committee, Fourth World Conference on Earthquake Engineering., Achisina, Casilla 2777, Santiago, Chile.

SESSION A 1

1 Engineering Estimates of Ground Shaking and Maximum Earthquake Magnitude. G. W. Housner.

2 Seismic Risk Studies in the United States. S.T. Algermissem.

3 Earthquake and Reservoir loadings. J.P. Rothe.

4 Statistical Inference of the Future Earthquake Ground Motion. Hisao Goto and Hiroyuki Kameda.

5 Earthquake Probability. W. G. Milne and A. G. Davenport.

6 The Major Influences on Seismic Risk. Allin Cornell and Erik H. Varmarcke.

7 A Physically Based Model to Simulate Strong Earthquake Rceord on Firm Grounds. Octavio Rascon and C. Allin Cornell.

8 Significance of Nonstationarity of Earthquake Motions. M. Amin, H.T. Ts' Ao and A. H. S. Ang.

9 Nondeterministic Analysis of Nonlinear Structures Subjected to Earthquake Excitations. Jose Penzien and Shi-Chi Liu.

10 Structural Response to Nonstationary Random Excitation. Hisao Goto and Kenzo Toki.

11 Simulated Earthquake Motions for Design Purposes. P. C. Jenning, G. W. Housner and N. C. Tsai.

12 An Earthquake Map of Chile. Cinna Lomnitz.

13 Seismicity Prediction : A Bayesian Approach. L. Esteva.

14 Response of Linear Systems to Certain Transient Disturbance. Emilio Rosenblueth and Jorge Elorudy.

SESSION A 2

15 Analysis of Strong–Motion Accelerograph Records. D. E. Hudson, N. C. Nigam and M.D. Trifunac.

16 On the Earthquake Motion for Aseismic Designing. Kiyoshi Kanai.

17 Characteristics of Earthquake Motion at the Rocky Ground. C. Tamura, T. Mizukoski and T. One.

18 Seismic Observation of Rigid Structures on Various Soils and Its Review. Kinji Akino, Tokiharu Ota and Hiroshi Yamara.

19 Influence of Geometry and Material Properties on the Seismic Response of Soil Deposits. I. M. Idris, H. Bolton Seed and H. Dezfulian.

20 Experimental Study on the Vibrational Characteristics of Ground. S. Yoshikawa, M. Shima and R. Irikura.

21 Control of Train Operation on the New Tokaido Line on the Occasion of Earthquake. Tatsuo Nishiki, Koichi Tamura and Masao Nonogaki.

22 Field Investigation of the Influence of Site Conditions on Ground and Structural Response. S. Cherry.

23 The Intensity of Ground Motion of the Skopje 1963 Earthquake. Apostol Poceski.

24 Strong Motion Records and Acceleration. William K. Cloud and Virgilio Perez.

25 Studies on the Spectra of Ground Vibrations Caused by Nearby Earthquakes. V.V. Steinberg.

26 Scale of Seismic Intensity. S. V. Medvedev.

27 Maximum Intensity of Ground Movements Caused by Faulting. N. N. Ambraseys.

SESSION A 3

28 Dynamic Analysis of Tall Building Founded in Deep Fill Materials. H, Sexton and R. J. Feibusch.

29 Brick Masonry Effect in Vibrations of Frames. Simon Lamar and Celso Fortoul.

30 Dynamic Elastic Analysis in the Design of Typical New Zealand High-Rise Buildings. R. Shephard.

31 Structural Dynamics of Cantilever-Type Buildings. John A Blume.

32 Torsion in Symmetrical Buildings. Nathan M. Newmark.

33 A Study on the Earthquake Response of Space Structures by Digital Computers. Kazuhiko Takeyama.

34 Response Analysis of Framed Structures. Y. Ohchi.

35 Spectrum Techniques for Tall Buildings. Paul C. Jennings.

36 Earthquake Response of Irregularly Shaped Buildings. Joseph Penzien.

37 Earthquake Analysis of Suspension Bridges. S. S. Tezcan and S. Cherry

38 Estimating Natural Frequencies and Modes of Arch Dams with the Theory of Plates of Elastic Foundation. Rudolph Szilard.

39 Time-History Response of Building with Unusual Configurations. John A Blume and Dilip Jhaveri.

40 Dynamic Earthquake Behaviour of Shell Roofs. R. W. Clough and A. J. Carr.

SESSION A 4

41 Factors Influencing the Inelastic Response of Multi-storey Frames Subjected to Strong Motion Earthquakes. B. P. Guru and A.C. Heidebrecht.

42 The Effect of Minimum Cross Bracing on the Inelastic Rcsponse of Multi-Storey Buildings. Robert D. Hanson and William F. B. Fan.

43 The Effect of Gravity on the Collapse of Yielding Structures with Earthquake Excitation. Raul Husid.

44 The Distributed Element Concept of Hysteretic Modeling and Its Application to Transient Problems. W. D. Iwan.

45 The Ultimate Strength of the Steel Structures Subjected to Earthquakes. Ben Kato and Hiroshi Akiyama.

46 Torsional Problems in Aseismic Design of High-Rise Buildings. Tadaki Koh, Hiromoto Takase and Tsunehisa Tsugawa.

47 Elastic and Inelastic Response of Framed Structures During Earthquakes. N.C. Nigam and G. W. Housner.

48 Non-Linear Response Analysis of Multi-Story Structures. T. Odaka.

49 Torsional Response of Building to Strong Earthquake Motions. Akenori Shibata, Junichi Onose and Toshio Shiga.

50 The Nonlinear Response of A Multi-Storey Prestressed Concrete Structure to Earthquake Excitation. R.A. Spencer.

51 Maximum deformations of Certain Non-linear Systems. A.S. Veletsos.

52 Response Spectra for Elastic and Elastoplastic Systems Subjected to Earthquakes for Short Duration. Apostol Poceski.

53 To the Final State of Rectangular Frames. Ryo Tanabashi, Yiyoshi Kaneta, Tsuneyoshi Nakamura and Shunzo Ishida.

54 The Inelastic Response of a Steel Frame. W.R. Walpole and R. Shepherd.

SESSION A 5

55 Pore-Water Pressures in Earth Slopes Under Seismic Loading Conditions. H. Bolton Seed and Kenneth L Lee.

56 Vibratory Compaction of the Soil and Tectonic Subsidence During the 1960 Earthquake in Valdiva, Chile. Eugenio Retamal and Edgar Kausel.

57 Densification of Sand by Vertical Vibrations. Robert V. Whitman, Pedro Ortigosa de Pablo.

58 Techniques for Field Measurements of Shear Wave Velocity in Soils. C. Martin Duke

59 Earthquake Analysis of Earth Dams. A. K. Chopra, M. Dibaj. R. W. Clough, J. Penzien and H B. Seed.

60 Mechanism of Earthquake Damage to Embankments and Slopes. Yashimasa Kobayashi.

61 A Study of Earth Dam Models Under Shock Loading. Jai Krishna, Shamsher Prakash, and S.K. Thakkar.

62 On Vibration Charcteristics of Fill Dams in Earthquakes. Isao Minami

63 Seismic Analysis of Earth Dams, Hatano T and H. Watanabe.

64 Earth Pressure Distribution Behind Retaining Wall During Earthquake. Shamsher Prakash and B.M. Basavanna.

65 Vibrations of Earth Dams During Earthquakes. I. M. Lavrov, G. A. Lyamzina and S.V. Medvedev.

SESSION A 6

66 Vibration Test of Structure Supported by Pile Foundation. K. Kubo.

67 Effect of Size and Shape of Foundation on Elastic Coefficients in a Layered Soil Mass. Shamsher Prakash and B.M. Basavanna.

68 Some Special Problems in the Design of Deep Foundations. S. B. Barnes.

69 Dam Foundation Interaction During Earthquakes. Anil K. Chopra, and P.R. Perumalswami.

70 Dynamic Analysis of a Structure Embedded in an Elastic Stratum. Hirishi Tajimi.

71 Some Effect of Substructure and Adjacent Soil Interaction on the Seismic Rcsponse of Building, J. Kazuo Minami and Joji Sakural.

72 A Method of Analysis for the Evalutaion of Foundation Structure Interaction. Edward L. Wilson.

73 Soil Structure Interaction of the Elevated Tower and of Concrete Footings. H. Kishida, K. Matsushita and I. Sakamoto.

74 On Earthquake Response of Elasto Plastic Structure Considering Ground Characteristics. R. Minami, T. Koborl and Y. Inone.

75 Equivalent Lumped System for Structure Founded Upon Stratum of Soil. Robert V. Whitman.

76 Elastic Soil Structure Interaction. J. Khanna.

77 Conventional Foundations and their Earthquake Problems. William T. Wheeler.

78 Oscillations of Tower Like Structures with Account of Inertia and Elasticity of Solid Medium. B.G. Korenev, V.A. Illjichijov and L.N. Reznikov.

SESSION B 1

79 Earthquake Measurements in and Around a Reinforced Concrete Building. Y. Osava, T. Tanaka, M. Murakami and Y. Kitagawa.

80 Study on the Large Scale Displacement Vibration Tests for the 1/25 Scale of the 17 Storied Building J.N.R. Chikaaki Ueda.

81 Vibration Tests and Test to Failure of a 7 Stories Building Survived a Severe Earthquake. Issao Funahashi. Katsuhiro Kinoshita and Hiroyuki Aoyama.

82 Observed Earthquake Response of Bridges. Elichi Kuribatasi and Toshi Iwasaki.

83 Vibration Studies of an Arch Dam. Tadahsi Takahashi.

84 Periods of Buildings of Mendoza City. Juan S. Carmona and Jose Herrera Cano.

85 A Method of Dynamic Model Test of Arch Dam. Shunzo Okamoto and Katsuyuki Kato.

86 Use of Response Method in Mechanical Modeling of Seismic Effects on Structures. Sh. G. Napatvaridze and P.A. Gutidze.

87 Summarized Report of Dynamic Tests of High-Rised Buildings and Co-operative Plan for Large Scale Vibration Test in Japan. The Group for Dynamic Test of High-Rised Buildings.

88 Dynamic Response of a 90 ft. Steel Frame Tower. N.N. Nielsen.

89 Response Testing of Multi–Storey Infilled Frames. D.V. Mallick.

90 Exprimental Results of the Dynamic Deformation of Multi–Story Building. H. Sandl and G. Serbanexcu.

91 Investigations into Earthquake Resistance of Large Panel Buildings. S.V. Polyakov, B.E. Denisov, T. Zh. Zhunusov, V.I. Konovodchenko and A.V. Cherkasna.

SESSION B 2

92 A Research Program on the Earthquake Resistance of Shear Wall Building. A. C. Heidebrecht and W.K. Tso.

93 A Vibration Test on Large Model Steel Frame with Precast Concrete Panel until Failure. R. Tamura, M. Murakami, Y. Osawa and N. Tanaka.

94 Low Cycle Fatigue Under Multi-Axial Stress Conditions. Koji Mizuhata.

95 On the Aseismicity of Precast Curtain Wall. Seiji Watanabe and Shozaburo Shimaguchi.

96 Damping Capacity of a Model Steel Structure. D. Rea, R. W. Clough, J. G. Bouwkamp and U. Vogel.

97 The Coupling of Reinforced Concrete Shear Walls. Thomas Paulay.

98 Evaluation of Inelastic Seismic Deformation of Reinforced Concrete Frames Based on the Tests of Members. Hajime Umemura and Hiroyuki Aoyama.

99 Seismic Behaviour of Reinforced Concrete Frame Structures. Vitelmo Bertero and Boris Bresler.

100 Repeated and Reversed Load Tests on Full-Scale Steel Frames. Lauren Carpenter and Le-Wu Lu.

101 Low Cycle Fatigue Fracture Limits of Various Kinds of Structural Members Subjected to Alternately Repeated Plastic Bending Under Axial Compression as an Evaluation Basis or Design Criteria for Aseismic Capacity. Minouri Yamada.

102 Research on Behaviour of Reinforced Concrete Constructions Under the Effect of Seismic Load. G.N. Kartsivadze and L.N. Avalishvill.

103 The Experimental Study on the Dynamic Behaviour of Reinforced Concrete Frames. Toshio Shiga and Jungi Ogawa.

104 An Exprimental Study on the Horizontal Restoring Forces in Steel Frames Under Large Vertical Loads. M. Wakabayasdi, T. Nonaka and Ch. Matsui

105 Bearing Capacity of Building Materials Under Dynamic Repeated Loading. S. V. Polyakov, H.V. Becheneva, Ju. I. Kotov and T.V. Potapova.

SESSION B 3

106 Research on the Behaviour of Steel Beam to Column Connections in the Seismic-Resistant Structures. Takeo Naka, Ben Kato, Makoto Watabe and Masami Nakao.

107 Reliability of Steel Beam to Column Connections Under Cyclic Loading. E.P. Popov and R.B. Pinkney.

108 Seismic Behaviour of Steel Beam to Column Connected Subassemblages. Vitelmo Bertero.

109 Variability Analysis of Shear Wall Structures. Jack R. Benjamin.

110 An Approximate Method of Static and Dynamic Analysis of Core-Wall Buildings. Sukenobu Tani, Joji Sakurai and Michio Iguchi.

111 Design of Beam Column Joints for Seismic Resistant Reinforced Concrete Frames. W. Gene Corley and Norman W. Hanson.

112 Seismic Moment Resisting Girder Connecting to Diagonally Aligned Columns. Sadaichi Terada and Akira Tsuruta.

113 Antiseismic Design of Multi-Storey Steel Frames by Plastic Methods. Oscar de Buen.

114 The Use of Steel to B. S. 968 : 1962 in the All-Welded Frame of a 19 Storey Building. G. Cooper.

115 Studies on Mechanisms to Decrease Earthquake Forces Applied to Buildings. Kiyoo Matsushita and Masanori Izumi.

116 Study of the Behaviour of a Hanging Building Under the Effect of an Earthquake. Carlos Jose, Oto Larios and Others.

117 Absorber System for Earthquake Excitations. Y.P. Gupta and A.R. Chandrasekaran.

SESSION B 4

118 Earthquake Analysis of Reservoir Dam Systems. Anil K. Chopra, E.L. Wilson and I. Farhoomand.

119 Study on the Earthquake Proof Design of Elevated Water Tanks. Y. Sonobe and T. Nishikawa.

120 Hydrodynamic Pressures Generated by Vertical Earthquake Component. A. Victoria Flores, L. Herrera and C. Lozano.

121 Seismic Design Criteria for Nuclear Reactor Facilities. Nathan M. Newmark and William J. Hall.

122 Water Dam Seismic Interaction. H. Sandi.

123 Selection of Design Earthquakes for Nuclear Power Plants. Joseph A. Fischer and William J. Murphy.

124 Hydrodynamic Pressures on Arch Dams During Earthquakes. Bhaskar Nath.

125 Dynamic Stresses of Underground Pipe Lines During Earthquakes. Akio Sakurai and Tadashi Takahashi.

126 Studies on the Earthquake Resistant Design of Suspension Bridge Tower and Pier System. Ichiro Konishi and Yoshikazu Yamada.

127 Some Long Span Construction in Earthquake Regions and Choice of the Structure on the Basis of Wave Dynamic Theory. V. A. Bykhovsky, F. V. Bobrov and E. S. Medvedeva.

128 The Effect of Seismic Action on the Dynamic Behaviour of Elevated Water Tanks. Mihail Ifrim and Christian Bratu.

129 Study of Earthquake Resistance of Boilers and Recommendations for their Design. Pavlyk. V.S,

130 Dynamics of Extended-in-Plan Structures in Strong Earthquakes. M.F. Barstein.

131 Earthquake Response Analysis and Aseismic Design of Cylindrical Tanks. S. Moran Garcia.

SESSION B 5

132 Seismic Forces and Overturning Moments in Buildings, Towers and Chimneys. Steven J. Fenves and Nathan M. Newmark.

133 Seismic Design of Traditional and Pre-Fabricated Reinforced Concrete Buildings. J. Ferry Barges and Artur Ravara.

134 Factors to be Considered in Calculating the Input Earthquake Force to Buildings. K. Matsushita, M. Izumi, Kuang-Jui Hsu and I. Sakamoto.

135 Comments on the New Chilean Seismic Code for Buildings. A. Arias, R. Husid and J. Monge.

136 Criteria for Earthquake Resistance Codes based on Energy Concept Draft Design Code. Cismigiu. Al., Titaru. Em. and Velkov. M.

137 Large Size Structures Testing Laboratory and Lateral Loading Test of a Five Storeyed Full Size Building Structure. Toshihiko Hisada representing Joint Committee on Housing Structures.

138 Earthquak Simulation by Shake Table. Enzo Lauletta and Aldo Castoldi.

139 Design and Research Potential of Two Earthquake Simulator Facilities. J.B. Bouwkamp R.W. Clough, J. Penzien and D. Rea.

140 Earthquake Engineering Research in the United States. N. Norby Nielsen and William H. Walker.

141 University of Chile-University of California Program in Earthquake Engineering. Martin Duke and Augustro Leon R.

142 A Probabilistic Model for Seismic Force Design. Jack R. Benjamin.

143 The University of Illinois Earthquake Simulator. M.A. Sozen, S. Otani, P. Gulkan and N.N. Nielsen.

144 The Problems of the Reliability and Optimality of the Earthquake Proof Structures. I.I. Goldenblat, N.A. Nicolaenko, J.N. Elsenberg and A.M. Zharov.

SESSION B 6

145 Seismic Behaviour and Design of Small Buildings in Chile. Joaquine Monge.

146 Strengthening of Brick Building in Seismic Zones. Jai Krishna and Brijesh Chandra.

147 Seismic Classification System for Old Buildings in New Zealand. C.M. Strachan.

148 Repairs on Power House and Boilers Support Structure Damaged by 1965 Earthquake. Ventanas 115 MW Steam Electric Station (Chile). Santiago Arias, Victor Arze and Jaime Bauza.

149 On One Method of Increaing the Seismic Stability of Brick Buildings. A.I. Churayan and Sh. A. Djabua.

150 Restoration of Stone Buildings after Earthquake. Rasskazovsky. V. T. and Abdurashidov K.S.

151 Earthquake Engineering as an Aid to Insurability. Frank Alberti.

152 Seismic Failure and Repair of an Elevated Water Tank. Elias Arze.

SESSION J 1

This session was devoted to the special papers prepared by a Rodrigo Flores, Kiyoshi Muto and Henry J. Degenkolb.

SESSION J 2

153 Observation of Damages of Industrial Firms in Niigata Earthquake. Heki Shibata and Sumiji Fujii etc.

154 Macroseismic Observations From Some Recent Earthquakes. N.N. Ambraseys.

155 Structural Engineering Aspects of the 1967 Adapazari Turkey Earthquake. Rifat Yarar and Semih S. Tezcan.

156 The Koyna, India, Earthquake. G. V. Berg, Y. C. Das, K.V.G.K. Gokhale and A.V. Setlur.

157 Lessons from Some Recent Earthquake in Latin America. Luis Esteva, Octavio A. Rascon and Alberto Gutierrez.

158 The Caracas Earthquake of July 29, 1967. Venezuelean Official Seismic Commission.

159 The July 29, 1969 Venezuela Earthquake Lessons for the Structural Engineer. Henry J. Degenkolb and Robert D. Hanson.

160 Behaviour of Tall Buildings During the Caracas Earthquake of 1967. J. Ferry Borges, J. Grases and A. Ravera.

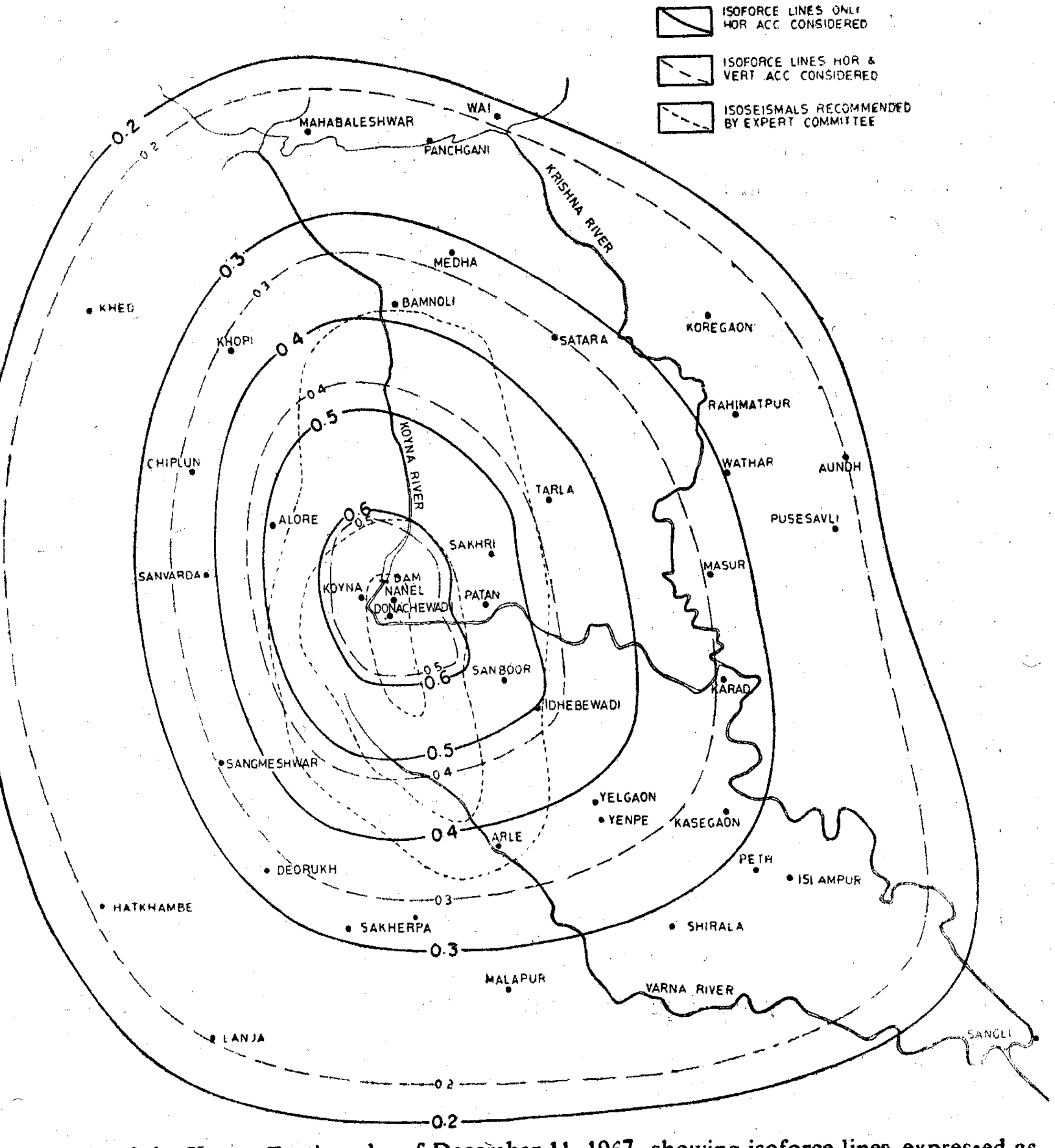
161 Damage Mechanisms and Design Lessons from Caracas. R.I. Skinner.

162 Implications on Seismic Structural Design of the Evaluation of Damage to the Sheraton-Macuto. M.A. Sozen, N.M. Newmark and G.W. Housner.

163 Caracas, Venezuela Earthquake of July 29, 1967. Diego Ferrer F. and Lloyd S. Cluff.

ISOFORCE MAP OF THE KOYNA EARTHQUAKE OF DEC. 11, 1967

Jai Krishna, A.S. Arya and Krishen Kumar (1969)* have prepared the ISOFORCE MAP of the Koyna Earthquake of December 11, 1967 on the basis of quantitative assessment of the forces acting on engineering structure and small objects located within a radius of 60 km. from Koynanagar. The lower and upper limits of the ground forces were determined by assessing the minimum force required for cracking of structures and sliding and overturning of objects as observed from the occurence and absence of these effects in the region. The distribution of ground acceleration at various places was plotted in the form of attenuation curves by graphical interpolation between the upper and lower limits of ground forces, and the isoforce map was prepared by joining points of equal ground accelerations.



Isoforce Map of the Koyna Earthquake of December 11, 1967, showing isoforce lines expressed as ground acceleration as fractions of acceleration due to gravity,

The peak values of ground forces as determined in this above manner should not be confused with design forces for structures. They give an estimate of the ratio in which the basic accelerogram could be toned down for obtaining the design values. as damage to structures depends on the integrated effect of the accelerogram and not the peak value alone.

* Distribution of the Maximum Intensity of Force in the Koyna Earthquake of December 11 1967" Unpublished Report, School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee. August, 1969.

Paper No. 79

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INELASTIC BEHAVIOUR OF MULTISTORY BUILDING DURING ERTHQUAKE

Brijesh Chandra* and A.R. Chandrasekaran**

Abstract

Various problems associated with earthquake resistant design of multistorey buildings are discussed. Inelastic behaviour, as studied by various investigators is reviewed to provide an insight into the problem.

Introduction

Earthquake resistant design of multistory structures is a complex problem. Building codes specify seismic coefficients for estimating the lateral forces to be considered for design of structures in potential seismic zones. These provisions are mostly based on the experience gained during past earthquakes and are suited to yield economical designs. However, a linear dynamic analysis of structure would indicate that the structure would be subjected to lateral forces much higher than those provided in the codes. From this, one would be inclined to think that structures designed according to code provisions would fail during an actual shock. This is not true. Structures designed to resist relatively smaller lateral force have stood major shocks, without much damage, in the past. This is due to the fact the behaviour of structures is far from linear. The structure dissipates a good deal of energy imparted to it through its non-linear or inelastic behaviour. A multistorey building dissipates energy through some non-structural members and through shear walls. In modern high rise construction, the non-structural elements are being cut down to a minimum to reduce weight of the structure and therefore the frames alone will be required to dissipate all the energy through its own elastic and inelastic action. A study of the inelastic behaviour of such frames is therefore of vital interest. Introduction of inelasticity in structural systems presents a number of computational problems. However with the help of some numerical methods and with high speed digital computer it is possible to analyse nonlinear multistory frames. This paper reviews the workdone by various investigators in this direction to be able to understand this problem.

Earthquake Response of Multistory Structures

During earthquakes, behaviour of multistory structures is essentially a vibration problem in which forces in structural members are computed from the dynamic displacements, velocities and accelerations. However, for obtaining these response parameters it is necessary to convert the building into a mathematically solvable model. This is a very important point and must be carefully examined as different results would be obtained by choosing different models.

A multistory building has been represented by a multiple–degree of freedom system with the columns providing the spring and the relatively rigid floors the masses. The equations of motion for a shear type multistorey framed system can be written in matrix form as follows :

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$$[M]\{\ddot{Z}\} + [C]\{\dot{Z}\} + \{R(Z)\} = -[M]\{\ddot{Y}\} \tag{1}$$

in which M is the mass matrix, C is a damping matrix R(Z) is the restoring force characteristics of springs, Y is the ground displacement and Z is the relative displacement. Dots represent differentiation with respect to time.

Two parameters in the above eqn. (1) need special mention. One, the damping properties represented by C and the other restoring force represented by R(Z). Damping in st uctures is present due to more than one reason. Friction at the joints, internal friction in material and air damping contribute to this factor. However, all these could be expressed to-gether by an equivalent viscous damping. For convenience, almost all the investigators represent damping in this form and assume this as present between two adjacent floors. This is also referred to as interfloor damping.

Regarding the restoring force characteristics, various investigators have chosen a variety of mathematical models viz. bilinear, elasto-plastic and nonlinear to mention a few. A detailed description of these follows :

Types of Non-Linearities

Fig. 1 shows the various types of nonlinearities considered by various investigators. These can be broadly classified into two catagories-elastic nonlinearity and hysteretic type. These have been mostlv adopted for the convenience in computations and are suitable for programming on a digital computer. Some experimental studies have shown that these mathematical models are not far from the actual behaviour observed in some materials of building construction.

Fig. 1(a) is a simple linear model in which the restoring force is directly related to the displacement Z through the stiffness matrix K. Mathematically,

$$\{R(Z)\} = [K]\{Z\} \tag{2}$$

Fig. 1(b) shows a hysteretic bilinear model in which the kink Y is the point where the structure starts yielding. Stiffness of such a member, beyond Y is reduced and the restoring force has to be defined in two parts as follows[1] :

$$R(Z) = (\mathrm{Sgn}\dot{Z})\,(K_1|\,Z_m\,| - F_n)\left(\frac{K_1-K_2}{K_1}\right) \text{ for regions of } K_1$$

$$R(Z) = (\mathrm{Sgn}\,\dot{Z})\,F_n\left(\frac{K_1-K_2}{K_1}\right) \text{ for regions of } K_2 \tag{3}$$

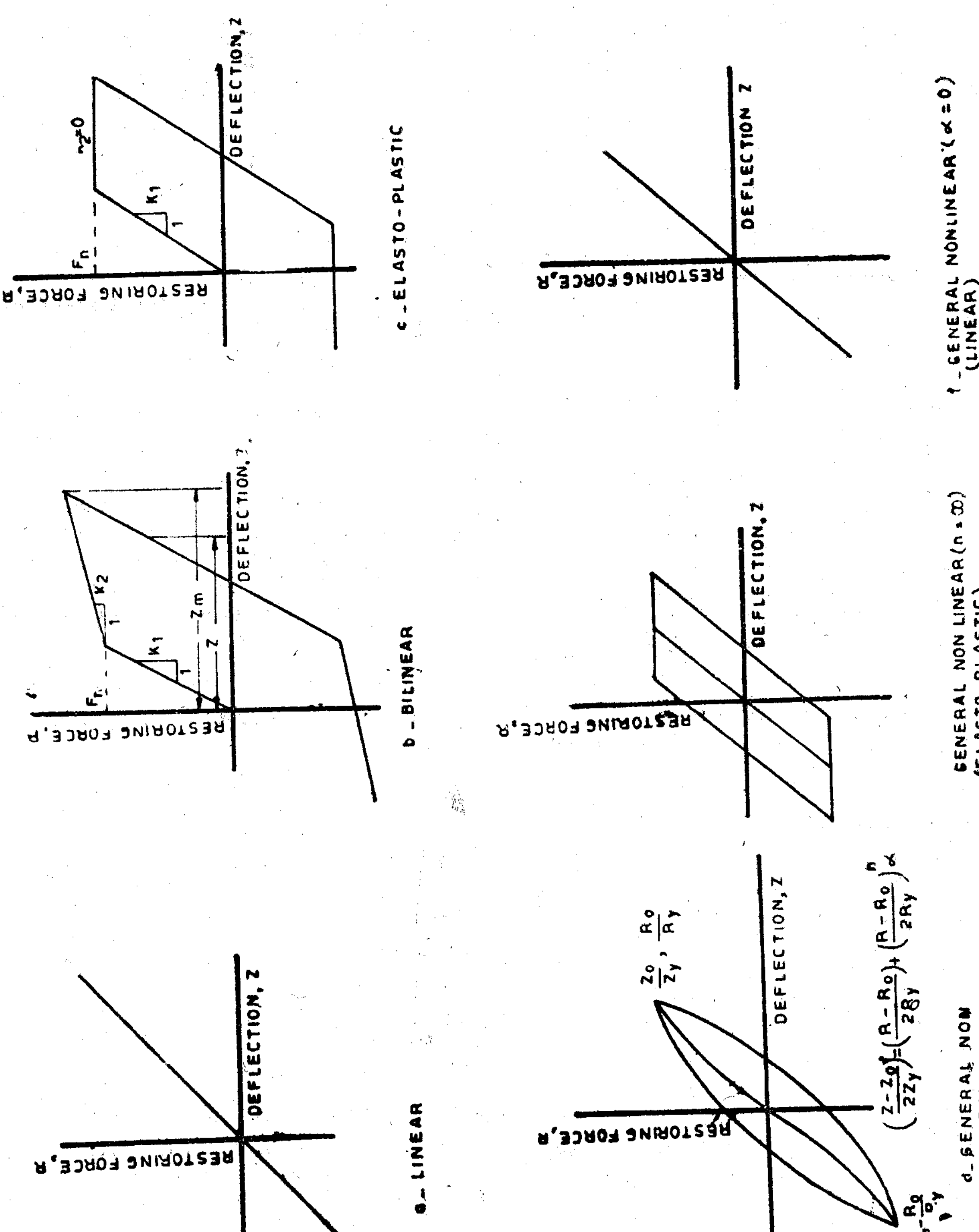
in which the various quantities are as indicated in Fig. 1 (b). The arrows marked on the figure indicate the position when loading is reversed. The elastic bilinear model retraces its skelton curve if loading is reversed.

Fig. 1(c) is a special case of bilinear model in which $K_2 = 0$.

Fig 1 (d) shows restoring force characteristics of a general nonlinear structure. This has been developed by Jennings [2] from the basic Ramberg-Osgood relationships [3]. This type of nonlinearity covers a wide range of mathematical models varying from linear to elasto-plastic. The force-displacement relationship can be expressed as follows :

$$\left(\frac{Z-Z_0}{2Z_y}\right) = \left(\frac{R-R_0}{2R_y}\right) + a\left(\frac{R-R_0}{2R_y}\right)^n \tag{4}$$

in which Z_0 is the displacement corresponding to restoring force R_0 at the time of reversal



RESTORING FORCE, R
DEFLECTION, Z
a _ LINEAR
F_n
K_1
K_2
Z
Zm
b _ BILINEAR
c _ ELASTO-PLASTIC
d _ GENERAL NON LINEAR
$\left(\frac{Z-Z_0}{2Z_y}\right) = \left(\frac{R-R_0}{2R_y}\right) + \left(\frac{R-R_0}{2R_y}\right)^n \alpha$
$\frac{Z_0}{Z_y}, \frac{R_0}{R_y}$
GENERAL NON LINEAR (n = ∞) (ELASTO-PLASTIC)
f _ GENERAL NONLINEAR (α = 0) (LINEAR)

Figure 1

and Z_y is the yield displaeement corresponding to yield forcɜ R_y, α and n are parameters to define the order of non-linearity.

The nonlinear structure therefore requires some more parameters to define it. The most important being the yield deflection or yield force. This is commonly referred to as the yield level'. In other words, yield level of a structure is defined as the lateral force which causes initial yielding in the structure.

Fig. 1(e) and Fig. 1(f) indicate the values of r and n which reduces the general non-linear system into elasto-plastic and linear system.

Methods of Solution

Whatever be the restoring force characteristics, the problem is to solve eqn. 1. For linear systems, the solutions are relatively simple and response cound be computed using the concept of response spectrum[4] and mode superposition principle[5,6]. However, for all other cases, no direct form of solution is available and invariably one has to employ numerical methods. Popular amongst these are the Euler's method, the Runge-Kutta third and fourth order methods, linear acceleration method and the corrector-predictor method. These have been dealt with in standard books [7,8,9,10] on numerical techniques and are not included here.

The corrector-predictor method is useful if the time increment used in the solution is uniform. Sometimes the input, earthquake data, may not permit use of this method as the time ordinates are unequally spaced. Studies [11,2] have shown that a maximum time increment of $T_p/40$ is necessary, otherwise results would be quite different and absurd. Kobayashi[12] felt that a time increment equal to 0·01 sec may be adequate for computation of structural response.

Electrical analogs have also been used to compute response[13], These are very handy and one can control a large number of parameters by means of switches on a panel. These are becoming obsolete now witn the advent of digital computers.

With the availability of highspeed digital computers now, numerical techniques are finding increased application in analysis. All the methods mentioned earlier are very suitable for programming on a digital computer and are extensively used by various investigators.

Response of Inelastic Systems - A Review of Results Obtained by Various Investigators

This subject has been the centre of interest for the last several years and continues to be so because of the complexity of this problem and the large number of variables that are associated with it. In what follows, a brief review will be made of the results obtained by various investigators so far.

Inelastic response of multiple degree of freedom systems was first studied by Berg[12] followed by a large number of investigators notably Clough[15,16,17] Penzien[18,19], Heidebrecht[20] and Tanabashi[21]. These studies presented a broad perspective of the various problems associated with computation of response in post elastic range.

The studies carried out by the various investigators can be grouped into two catagories. On group studies determination of response of multistory buildings with arbitrary theoretical stiffness distribution and yield levels in various storeys. As such these provide some guidelines for predicting behaviour of buildings. The contributions in this group are due to Berg[14], Clough et al[17], Penzien[19], Bycroft[22], Berg and Thomaides[23], Hisada et al [24], Ibanez[25], Berg and Dedeppo[26], Saul et al[27], Veletsos[28], Poceski[29], and Giberson[30]

These investigators have used one or more earthquakes for the purpose of computing response. These earthquakes are generally El Centro May 18, 1940, Taft July 21, 1952 and the artificial shocks developed at the California Institute of Technology[31].

The second group studies response of certain special buildings that are either already existing or are specially chosen for the purpose of the study. Investigators in this group include Clough[17], Giberson[30], Berg[32], Kuroiwa[33], Walpole and Shepherd[34], and Spencer[35].

The studies mentioned above cover steel, reinforced concrete and prestressed concrete buildings represented by various models mentioned in earlier paragraphs.

Discussion of Results

Response of structures has been examined from different angles by various people. However, they all seem to agree that introduction of inelasticity in a structure results in reduction of structural response. It is due to this that structures designed to resist very little lateral force are able to withstand moderate shock with little or no damage. Whereas most of the investigators report that, generally, inelastic deformations are less compared to those of an associated linear system, Clough, et al[17] report that it is the other way round. However, they observe that these deformation vary widely through the structure itself. Hisada, et al[24] have reported that inelastic deformations are about the same as that of an associated linear system. Veletsos[28] observes that the relationship between maximum inelastic deformations and deformations of associated linear systems is the same as that for a single degree of freedom system with the same period and subjected to same excitation. He shows that displacements in inelastic systems are not equal to linear systems and gives the ranges of periods where displacements are lower, equal and higher than linear systems.

Effect of Fundamental Period on Inelastic Response

The inelastic deformation spectra obtained[19,23,21,25] shows that fundamental period of structure is an important parameter in determining response. Like the displacement spectra of linear systems, inelastic response in all storeys increases generally with the increase in fundamental period.

Larger displacements as would be expected in structures of relatively larger fundamental periods could prove disasterous. Ibanez[25] has stressed this point and has suggested that functional failure may occur due to displacement rather than overstressing.

Effect of Yield Level

Yield level is the parameter that defines the magnitude of lateral force which causes the structure to start behaving inelastically. (This parameter is therefore a property of the structure). This is commonly expressed in terms of fraction of acceleration due to gravity and assumed to act at floor level.

Berg and Thomaides[23], Penzien[19], Poceski[29], Wen and Janssen[36] and others conclude that for earthquake type excitation, response gets reduced with decrease in yield level. Also, maximum response is associated with highest yield level. However, Penzien[19] observes that there is a certain optimum yield level below which elasto-plastic response increases. He suggests this level as 0 10 g for tall flexible structures with long periods and 0.20 g for stiff structures with short period. These values were suggested only for El Centro shock of May 18, 1940 and should not be taken as universal. Berg and Thomaides[23] are are of the opinion that this level is 0.06 g. They also observe that decrease in yield level is accompanied by decrease in total input energy at all levels of damping.

Effect of Stiffness Distribution

This aspect has received relatively less attention so far. Bycroft[22], Hisada et al[34] and Veletsos[28] have studied the effect of stiffness distribution on the inelastic response of structures. The ratio of top storey stiffness to bottom storey stiffness (K_T/K_B) has been kept varying linearly from 0 1 to 0.5 for a twenty storey building[24]. It was found that in structures with linear stiffness reduction towards higher storeys, maximum storey displacements increase remarkably in upper storeys but decrease in lower storeys. On the basis of that study, reasonable equitable distribution of ductility in various storeys can be expected if K_T/K_B is equal to 0.20.

Bycroft[22] assumed a linear variation of stiffness (K_n) and strength (G_n) with height h as follows

$$K_n \propto (1 + \rho \, . \, Z_n/h)$$
$$G_n \propto (1 + \rho \, . \, Z_n/h) \qquad (5)$$

in which Z_n = position of point midway between $(n-1)^{th}$ and n^{th} floors measured from top of structure. $\rho = 0$ corresponded to a uniform building. Studies indicated that ρ is vital in deciding about response in inelastic systems but not so in elastic systems. He and Veletsos[28] felt that optimization of ρ is a difficult task. If this were possible, economic designs of multistory frames would be worked out distributing the plasticity over the height of the structure.

Effect of Ground Motion

The results presented by various investigators would be comparable only if everyone choses the same accelerogram for computations. As long as this is not there, the results will have only limited qualitative usefulness. Studies carried out by Gibreson[30] recently, have indicated that response characteristics are determined by properties of structures rather than the earthquakes. These conclusions have been drawn by him after a detailed study of a twenty storeyed structure subjected to seven different earthquake motions. However, most people present results for particular shocks only and warn against making any generalized conclusions for earthquakes in general.

Other Effects

While attempts are being made to understand the structural response in inelastic range, some studies on secondary effects have also been reported.

Goel[37] has studied the effect of axial deformations on the inelastic response of frames subjected to earthquakes. It is found that response is affected to the tune of 10 to 20% by considering this aspect.

Nigam[38] has shown that inelastic response depends on the interaction between forces and displacements at a section during the process of yielding. He concludes that significant changes in response could be expected due to this interaction and presents a series of curves to show this effect. Use of these curves for inelastic design has also been explaind by him.

Kobori et al[39] have considered the effect of ground compliance on elasto-plastic structures and conclude that response is greatly affected to this.

Odaka et al[40] analysed some actual multistoreyed structures having steel frames with reinforced concrete walls for the Kanto earthquake considering bilinear characteristics and could explain the damage caused to these during this shock. However, he observed that distribution of ductility is quite different in different types of buildings.

Conclusions

The foregoing analysis of the problem of inelastic response shows that this field is attracting attention of a number of investigators. It is interesting to see that the same problem has been attempted by many people employing various numerical methods. The results obtained by them are sometimes not consistant and are even contradictory to findings of some others. Housner[41] points out that this difficult field is associated with complicated problems and it is difficult to grasp the general significance of computations. The problem needs examination from the point of view of design of structures. In an elastic analysis, the base shear and distribution of shear is suggested based on consideration of various parameters. On the other hand, in a nonlinear case, it would be useful to proportion the members such that same ductility is obtained in all the storeys. This sort of optimization would be rather difficult to achieve, but it would be quite useful to have a relationship between the intensity of ground motion and the maximum ductility in a structure.

It is hoped that future work on this problem will examine the above points and will clarify the doubts that have been raised due to inconsistencies in various reported investigations.

Acknowledgements

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Abstract

PRE-CAMBRIAN STRATIGRAPHY AND GEOCHRONOLOGY OF PENINSULAR INDIA By S.N. Sarkar, Professor and Head of the Dept. of Applied Geology, Indian School of Mines, Dhanbad, Dhanbad Publishers, India December, 1968

On the basis of systematic stratigraphic tectonic and metamorphic studies in certain critical Pre-Cambrian regions in Peninsular India and Ceylon, reinterpretation of all relevant data from the other areas, and more than 500 radiometric age data (by K-Ar, Sr-Rb and Pb isotopic and isochron methods) available upto date, the author has suggested a revised correlation and classification of the Pre-Cambrians of this subcontinent and has established a generalised succession of the dated orogenic cycles and phases. Some of the important conclusions are :—

(a) The Older Metamorphic Group of Singhbhum represents the oldest orogenic belt (c. 3200 Myr) recognisable in India, and there are evidence of the presence of Basement Complex older than 3000 Myr in Rajasthan, Mysore and Madras.

(b) The Dhawar, Iron Ore, Charnockite-Khondalite (Eastern Ghats I), B.G. Complex and Bundelkhand cycles accompanied by widespread granitic activity, closed between 2500 and 2700 Myr and are broadly correlatable. These represent the relics of continental nucleii older than c. 2500 Myr. Within the younger belts the relics of the older basement are often present.

(c) Singhbhum orogenic cycle in Singhbhum-Gangpur region (closing at c. 850 Myr), is correlatable with metamorphism and granitic activity in Gaya (955 Myr), Gurpa (930 Myr), Ranchi-Muri (890-970 Myr), Dhanbad (893-1086 Myr) and Sausar (864-996 Myr) regions and all belong to the Satpura cycle, which again may be provisionally correlated with the Aravalli cycle closing at c. 950 Myr.

(d) The deposition of Singhbhum, Gangpur and Dhanjori groups took place between c. 1700 and c. 2000 Myr, of Kolhans at c. 1600 Myr and of Aravallis at c. 2000 Myr (?)

(e) In the Cuddapah basin (type area) deposition commenced at c. 1500 Myr and Cuddapahs are correlatable with the Kaladgis. The sedimentation of the Lower Vindhyans (type area) commenced at c. 1100 Myr and the Upper Vindhyans at c. 920 Myr. Vindhyans may be broadly correlated with Kurnools, Bhimas and Badamis.

(f) Delhi cycle closed ot c. 750 Myr and Malani and Khetri phases are still younger (c. 600 Myr). Prominent metamorphic and/or granitic activity affected part of S. India at c. 2000, 700-800 Myr, Eatern Ghats belt at c 1600 Myr, Madhya Pradesh at c. 2100, c. 1450-1750, c. 1300 c. 900 Myr.

(g) A pronounced orogenic-metamorphic cycle with granitic activity (c. 450-600 Myr is recognisable in different parts of India e. g. Rajasthan, Monghyr, Assam, Eastern Ghats, Travancore and Ceylon (Indian Ocean cycle).

(h) The orogenic metamorphic cycles closing at about 3200, 2600, 2000, 1600, 900 and 600 Myr in India are broadly correlatable with the corresponding orogenic events recognised in other continental shield areas of the world. The Indian Pre-Cambrians may be provisionally grouped as follows :—

Pre-Cambrian V (600-900 Myr) :	Chattisgarh basin, Up. Vindhyan, Khairagarh, Malani, Monghyr (?)
Pre-Cambrian IV (900-1600 Myr) :	Cuddapah, Lo. Vindhyan, Satpura, Aravalli and Delhi.
Pre-Cambrian III (1600-2500 Myr) .	Satpura and Aravalli (in part), Amgaon, Eastern Ghats (II).
Pre-Cambrian II (2500-3000 Myr) :	Iron ore, Dharwar, B.G. Complex, Bundelkhand, Eastern Ghats I).
Pre-Cambrian I (3000-3500 Myr) :	Older Metamorphics (Bihar, Orissa), Basement Complex (S. India, Rajasthan).

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A STUDY OF CODE PROVISIONS FOR THE DESIGN OF FRAMED STRUCTURES

Brijesh Chandra* and S.K. Mital**

Introduction

Many countries are today faced with the problem of designing structures to resist earthquakes. Some countries have already formulated building codes[1], giving due consideration to the earthquake occurences in the past and providing adequately to strengthen the buildings against the forces resulting from an earthquake shock. Some other countries are also following through and are formulating such codes.

In these codes, the earthquake forces are taken into consideration as static lateral forces, which do not take into account the properties of the structure, viz. the period and damping. Almost all these codes provide lateral forces, much lesser than those indicated by a dynamic analysis using response spectrum. However, it has been observed that the structures so designed have withstood strong motion shocks without much damage. This behaviour could be explained by the inelastic properties of the structure and its enormous energy absorbing capacity[2] However. one must know before hand as to how much the reserve energy a structure has got so that it could be estimated as to what size of earthquake could be resisted by it at a particular distance from the epicentre.

This paper examines the order of reserve energy capacity of simple framed structures designed according to the I.S. Code 1893–1966[3].

I.S. 1893–1966 Provisions

For framed structures, the I.S. Code[3] specifies that the total base shear V_B is given by

$$V_B = C \alpha W \quad (1)$$

in which C is a coefficient defined by the flexibility of the structure, and is given by $\frac{9}{N+5}$ but is not greater than 1.

N is the number of storeys

α is the seismic coefficient

W is the total dead load and appropriate live load.

The lateral force along the height of the structure (Fig. 1) at a point i is given by Q_i

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{i=1}^{N} W_i h_i^2} \quad (2)$$

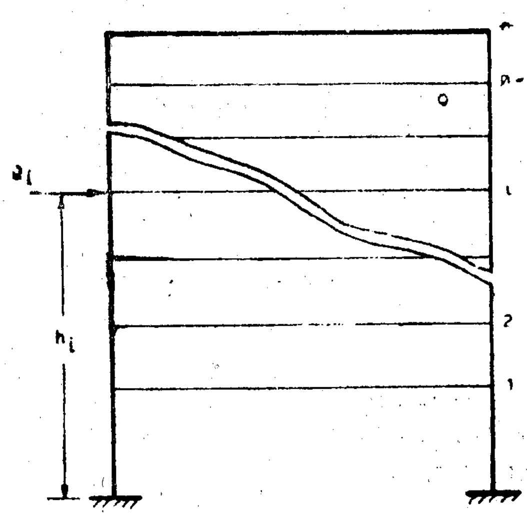

Fig. 1. Lateral Loading on a Multi-Storey Frame.

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The Response Spectrum

Response spectrum[4] is defined as the maximum response of a single degree freedom linear system to a prescribed exciting ground acceleration, plotted against the natural period for various fractions of critical damping. The relative velocity response spectrum S_v is mathematically given by

$$S_v = \left[\int_0^t \ddot{y}(T)\, e^{-p\zeta (t-T)} \,\mathrm{Sin}\, p_d (t-T)\, dT \right]_{max} \quad (3)$$

in which $\ddot{y}$ (T) is the ground acceleration
ζ is the fraction of critical damping
p is the natural frequency
p_d is the damped natural frequency $= p\sqrt{1-\zeta^2}$

This is a complex function due to $\ddot{y}$ (T). Fig. 2 shows the accelerogram for El Centro Earthquake of May 18, 1940. The velocity spectrum is related to the displacement and acceleration spectrum as follows

$$S_d = \frac{1}{p} S_v \quad (4)$$

$$S_a = p\, S_v$$

The velocity spectrum of El Centro Earthquake of May 18, 1940 is also shown in Fig. 2. Housner has studied spectra for a number of earthquakes. It is observed that the spectra for various earthquakes are of the same pattern. On the basis of this. Housner plotted what are known as average spectrum curves [5]. Fig. 3 shows the average velocity curves. These spectrum values multiplyied by factor N, (called Multiplying factor) obtained for each earthquake shock, gives the value of response for the respective earthquake.

The parameter S_v is of great significance. Once S_v is determined, we can know the maximum force experienced by the structure. The maximum force F_{max} is given by

$$F_{max} = K\ (x-y)_{max} \quad (5)$$

in which K = stiffness, and (x−y) = the relative disolacement of the mass with respect to the base. In terms of the seismic coefficient, C_s

$$F_{max} = C_s.\ W = K.\ \frac{S_v}{p}\ .\ \frac{W}{mg}$$

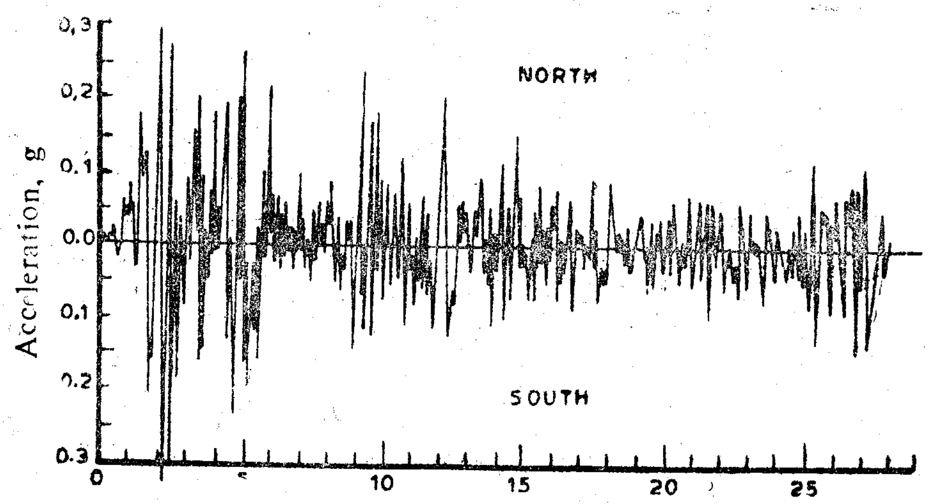
$$\text{or} \quad C_s = \frac{2\pi}{T}\ \frac{S_v}{g} \quad (6)$$

N-Value Based on code

Using the average spectrum curves, the multiplying facter N, can be worked out by equating a the seismic coefficient given in the code to the dynamic coefficient C_s.
From this,

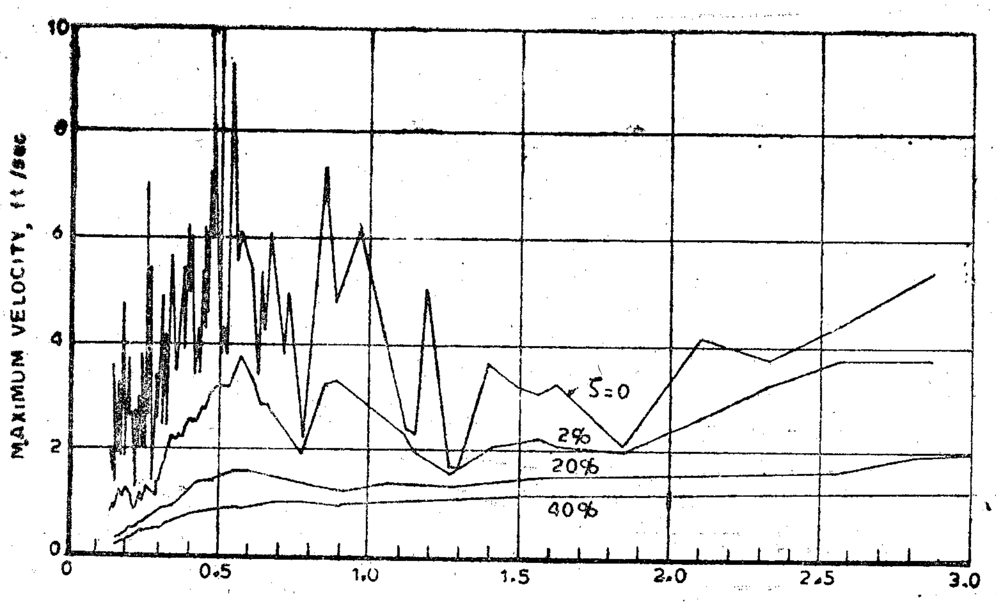
$$N = \frac{a}{\frac{2\pi}{T}\ .\ \frac{S_v}{g}} \quad (7)$$

A plot of N and T is shown in Fig. 4 for 5 and 10 percent damping. This shows that even for large values of the period and high damping, the values of N worked out for



Duration sec

(a) Accelerogram



Undamped Natural Period, sec

(b) Velocity Spectra

Fig. 2. Acceleregram and Velocity Spectra of El Centro, May 18, 1940 Shock (Component N-S)

code forces is very small. In India we have experienced earthquakes with stronger ground motions than these. Ground accelerations upto about 63% g were recorded in Koyna Earthquake of Dec. 11, 1967.

Therefore it would appear as though the provisions of the code are inadequate. However, considering the elastoplastic behaviour, structures will generally be found safe. This is illustrated by the following example.

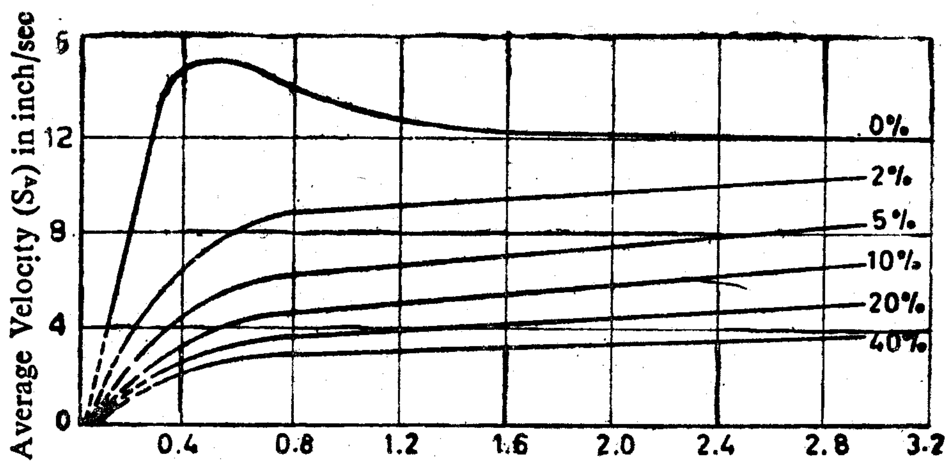


Fig. 3. The Standard Velocity Spectra

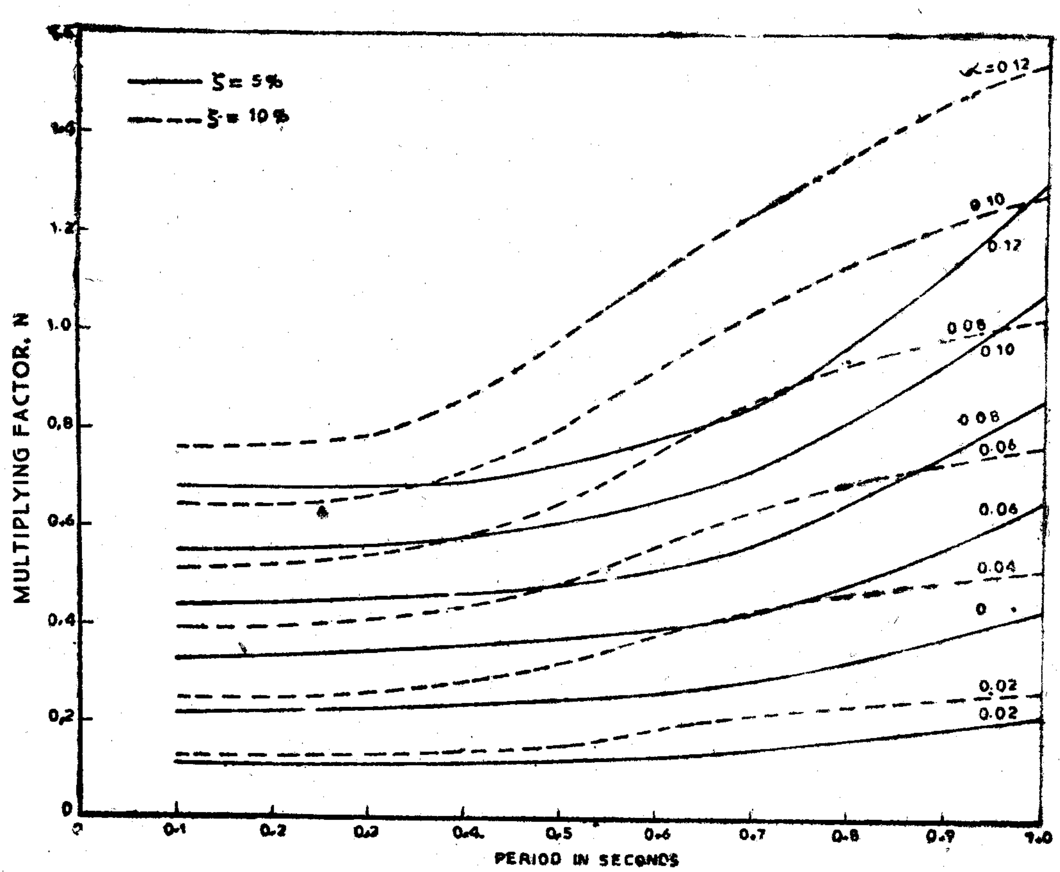


Fig. 4. Multiplying Factory corresponding to Different Seismic Coefficients for Various Periods and Damping ratios.

The Example

A portal frame shown in fig. 5 is to be designed for the following conditions

(a) Earthquake force as given by I.S. 1893-1966.

(b) Earthquake force as expected on the structure at the site and considering dynamic elastic response.

(c) Earthquake force same as in (b) but considering the frame to be elasto-plastic

W = Total vertical load
h = Height of portal
L = Length of portal
I = Moment of inertia
E = Modulus of elasticity
ζ = 5%

The beam is assumed to be rigid.

The frame is to be situated in Shillong at a distance of 30 miles from the epicenter of an earthquake of Magnitude 7.5, and focal depth 15 miles.

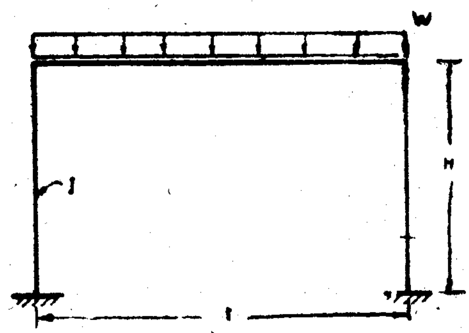


Fig. 5. Vertically Looaded Portal Frame

For the site the I.S. 1893-1966 specifies a seismic coefficient of 0.12. Also from the data of expected earthquake the maximum ground accelerations expected at the site would be about 0.33 g[6]. Considering the characteristics of the ground motion to be similar to those of El Centro May 18, 1940 shock it would be reasonable to assume a multiplying factor of 2.7 for the site.

Case (a) Elastic response

According to I.S. 1893-1966 the horizontal static force H for the frame in zone VI works out to be 0.12W.

The bending moment caused in the columns for this force H is given by $\frac{Hh}{4}$ or 0.03 Wh.

Case (b) Elastic response during earthquake

The stiffness K of the frame given by

$$K = \frac{24\ EI}{h^3}$$

and the period T is given by

$$T = 2\pi\sqrt{\frac{Wh^3}{24\quad g}} \qquad (8)$$

The parameter W, h, E and I are so chosen that the frame has periods of 0.5, 0.6 and 0.7 seconds respectively. Using the average velocity spectrum curves the moment are calculated in Table 1.

TABLE 1

Period T sec	Spectral velocity S_v	$\Delta = \frac{T}{2\pi} S_v N$	$\frac{EI}{h^2} = \frac{0.0515}{T^2} Wh$	Moment $= \frac{6 EI \Delta}{h^2}$
0.5	0.42	0.09	0.206 wh	0.112 wh
0.6	0.45	0.116	0.143 wh	0.099 wh
0.7	0.48	0.145	0.105 wh	0.092 wh

Case (c) Elasto-plastic response during earthquake

For this case, the concept of reduction factor will be used. According to this, a non-linear system may be related to linear system through a reduction factor(7). This is defined as a factor by which the seismic coefficient for a linear system be reduced so as to arrive at the seismic coefficient for a non-linear system. This means that the design of a non-linear system with a certain ductility ratio can be based on the knowledge of an equivalent linear system, where the structure is designed elastically for the toned down earthquake.

Response of non-liner systems with various characteristics has been studied in detail. From this study reduction factors have been worked out for non-linear systems for various ductility ratios(7).

It is considered reasonable to assume that a structure is capable of having ductility of the order of 3 to 5. For these values, reduction factors for the El Centro Earthquake have been worked out and are tabulated in table 2. Dynamic moments resulting from this are also tabulated in table 2. It may be seen that the moments in this case are much less than those obtained in 'elastic' case. Also, these are lower than those obtained from the consideration of code coefficients.

TABLE 2

Period T	Ductility ratio	Reduction factor	Dynamic moment for elasto-plastic response
0.5	3	4.6	.0244 wh
0.5	4	6.4	.0175 wh
0.5	5	8.4	.0133 wh
0.6	3	4.26	.0232 wh
0.6	4	5.84	.017 wh
0.6	5	7.6	.013 wh
0.7	3	3.92	.0235 wh
0.7	4	5.28	.0174 wh
0.7	5	6.8	.0135 wh

Conclusions

It is seen that a structure designed statically according to code is theoretically overstressed, but survives a strong earthquake, because of its non-linear properties. The code provisions which appear to be inadequate are really not so because of the inelastic behaviour that is associated with structures.

Acknowledgement

The problem was suggested by Dr. Jai Krishna, Professor and Director, S.R. T.E.E., Roorkee. Authors are thankful to him for his valuable suggestions and for the permission to publish this paper.

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FOURTH SYMPOSIUM ON EARTHQUAKE ENGINEERING
ROORKEE (U.P.), INDIA

(November 14, 15 and 16, 1970)

(Jointly sponsored by the **University of Roorkee** and **Indian Society of Earthquake Technology**)

The University of Roorkee and the Indian Society of Earthquake Technology cordially invite Engineers and Scientists interested in the field of Earthquake Engineering and Seismology to participate in the **Fourth Symposium on Earthquake Engineering** proposed to be held at Roorkee in November 1970.

The sessions are proposed to be divided broadly into the following themes :

Structural Response and Design of Structures for Earthquake and Blast Forces.
Design of Dams and Appurtenent Works in Earthquake Zones.
Housing in Seismic Zones and Damage during Recent Earthquakes.
Soil and Foundation Behaviour During Earthquakes.
Instruments for Earthquake Engineering and Seismological Studies.
Seismicity, Wave Propagation and Ground Motion.
Seismo-Tectonic Studies of Seismic Regions.
Observation of Earthquake Damage and Determination of Isoseismal and Iso-Force Lines.

The language of the Symposium will be **English.**

Each author is requested to send a synopsis of his proposed paper not exceeding 300 words by March 31, 1970. The last date for submission of full papers, in duplicate, limited to equivalent of 6000 words including Tables and Figures to reach Roorkee is June 30, 1970. Early advice of papers would greatly assist the organisers in drawing up the final programme.

It is planned to print all accepted papers prior to the opening of the first session of the symposium for distribution to all registered participants. Those interested are requested to kindly send their contributions as early as possible.

The organisers will be grateful if the receivers of this circular will assist in bringing it to the notice of all others who may be interested in this symposium.

All correspondence may please be addressed to the Secretary, Organising Committee, Fourth Symposium on Earthquake Engineering, **School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee, U.P., India.**

Paper No. 81

Bulletin of the Indian Society of Earthquake Technology, Vol. 6, No. 4, pp. 185–194, Dec. 1969

A NOTE ON THE SEISMIC ZONING MAP OF INDIA*

L. S. Srivastava

Abstract

The paper describes the basis and procedure adopted in the preparation and revisions of the Seismic Zoning Maps of India adopted for use in Indian Standard Recommendations/ Criteria for Earthquake Resistant Design of Structures and Code of Practice for Earthquake Resistant Construction.

Introduction

Based on the available data on geology, tectonics and past earthquake occurances, various attempts have been made to prepare earthquake zoning maps of India. In these maps the country was divided into three to four zones indicating, probable occurrence of the earthquakes (frequent, occassional, few) or probable accelerations (10 to 30 percent gravity, less than 10 percent gravity, ete.,) or likely intensity of damage (heavy, moderate, slight, etc.) or factor of safety to be adopted in the design of structures etc. These maps thus served limited purpose. With the development of earthquake engineering studies in the country, a systematic study of the various aspects of the earthquake problems was initiated and it was felt that standard recommendations for the earthquake resistant design of structures be prepared and the seismic risks involved in various parts of the country be indicated. The Indian Standards Institution, which was entrusted with this problem, brought out the first Indian Standard Recommendations for Earthquake Resistant Design of Structuees (IS:1893-1962) in 1962. This note describes in brief the basis which appears to have been followed in the preparation of the seismic zoning maps of India incorporated in this standard and its subsequent revisions.

1962 Seismic Zoing Map

In the formulation of the Indian Standard Recommendations for Earthquake Resistant Design of Structures it was considered necessary to have a seismic zoning map to indicate broadly the seismic coefficients that could generally be adopted for design in different parts of the country, though it was noted that the seismic coefficients used in the design of any structure is dependent on many variable factors and a rigorous analysis considering all the factors involved has got to be made in the case of all important projects in order to arrive at suitable seismic coefficients for design. With this in view a seismic zoning map dividing the country into various zones was prepared giving for each zone a reasonable estimate of the intensity of earthquake which will occur in the event of a future earthquake. The map prepared had seven zones and was prepared considering that a rational approach to the problem would be to arrive at a zoning map which show the maximum intensity (M.M. Intensity scale) of earthquakes likely to occur at each point based on data of the known earthquakes, assuming all other conditions as being average, and to modify such an average idealised isoseismal map in the light of tectonics, geology, soil conditions and the maximum intensities as recorded from damage surveys.

The following procedure appears to have been followed in preparing 1962 seismic zoning map shown in figure 1 : (1) the epicentres of all known earthquakes of magnitude 5

* Detailed comments on this note are solicited.

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and above and Maximum intersities at various points were plotted from the isoseismals of major earthquakes for which records were available. Since the 1819 Kutch Earthquake, 1897 and 1950 Assam Earthquakes, 1905 Kangra Earthquake, and 1934 Bihar Nepal Earthquake were of very high magnitudes, they adequately encompassed the effects of the lesser magnitude earthquakes occurring in the different regions. In addition to the great earthquakes of the country, other earthquakes taken into consideration were a few smaller earthquakes in the Himalayas, Delhi Earthquakes, Satpura and Rewa Earthquakes, Bellary Earthquake and the zone of minor tremors from Trivandrum to Madras and East Coast regions. (2) After plotting the idealised isoseismals for the earthquakes, enveloping lines for the different M.M. Intensities were drawn. These lines were modified where necessary, taking into account the magnitude of intervening earthquakes, local ground conditions, principal tectonic trends as portrayed in the preliminary Tectonic Map of India prepared by the Geological Survey of India in 1962, basement configuration of the Indo-Gangetic Plains and other alluvial basins as revealed by geophysical surveys of the Oil and Natural Gas Commission and the likely trend of the Gango-Brahamputra rift postulated by Mithal and Srivatava (1959). Thus in modifying the isoseismals of the Delhi Earthquake these were elongated in the direction of the trend of Aravallis, a higher elliptical zone was made following the Moradabad fault, and the isoseismals east of Barielly following Uttar Pradesh-Nepal Border were made along the likely trend of the Gango-Brahamputra rift. The isoseismals for the Satpura Earthquake were drawn as circular as its connection with the Narbada rift was not surmised. The Bellary Earthquake isoseismals were elongated roughly parallel to the zone of minor tremors from Trivandrum to Madras, which itself was tentatively delineated parallel to east coast lineament in the absence of other definite data. (3) After drawing the modified isoseismals, the zones with M.M. Intensity, V, VI, VII, VIII, IX and "X and above" were designated as seismic zones I, II, III, IV, V and VI and the region with M M. Intensity less than V was designatad as seismic zone 0. This "zero zone" was not a zone of "zero earthquakes", but the designation was given to suggest that no earthquake problems of any significance may occur in this region.

1966 Seismic Zoning Map

During the revision of the IS : 1893–1962, it was felt that the additional knowledge of geology, tectonics and earthquakes, made available in subsequent years. requires modifications in the 1962 zoning map. This revision took into account the detailed Tectonic Map of India (1963) and additional data on earthquakes for which instrumental records were not available and for which the magnitude values were evaluated by the India Meteorological Department on the basis of the felt area. The 1966 seismic zoning map also followed the same general approach as for the 1962 map, except that a greater recognition was given to the tectonic features. Figure 2 shows the 1966 Seismic Zoning Map (IS : 1893–1966). The following major modifications were affected in this revision ; (1) The marked embayment in zone II and III in Uttar Pradesh was reduced and was kept parallel to the prevailling tectonic trend of the Himalaya and marginal depression of the shield. (2) The seismic status of the Delhi and surrounding regions was increased from III with an elliptical eyelet of zone IV to zone IV in general on the basis of the earthquake frequency studies carried out by the India Meteorological Department and recent earthquake activity related to the hidden Moradabad fault in the basement of the Gangetic plains, and the Sohna and other faults in the Delhi quartzites. (3) The location of the Kangra Earthquake was corrected and the isoseismal of M.M. Intensity. "X and above" was demarcated similar to that actually observed during the earthquake. This area of high intensity was given the designation of zone VI and seismic status of the region was thus enhanced. A region surrounding this high zone was demarcated as zone V on magnitude-intensity-distance relationship. (4) The seismic status of the north-west part of Kashmir

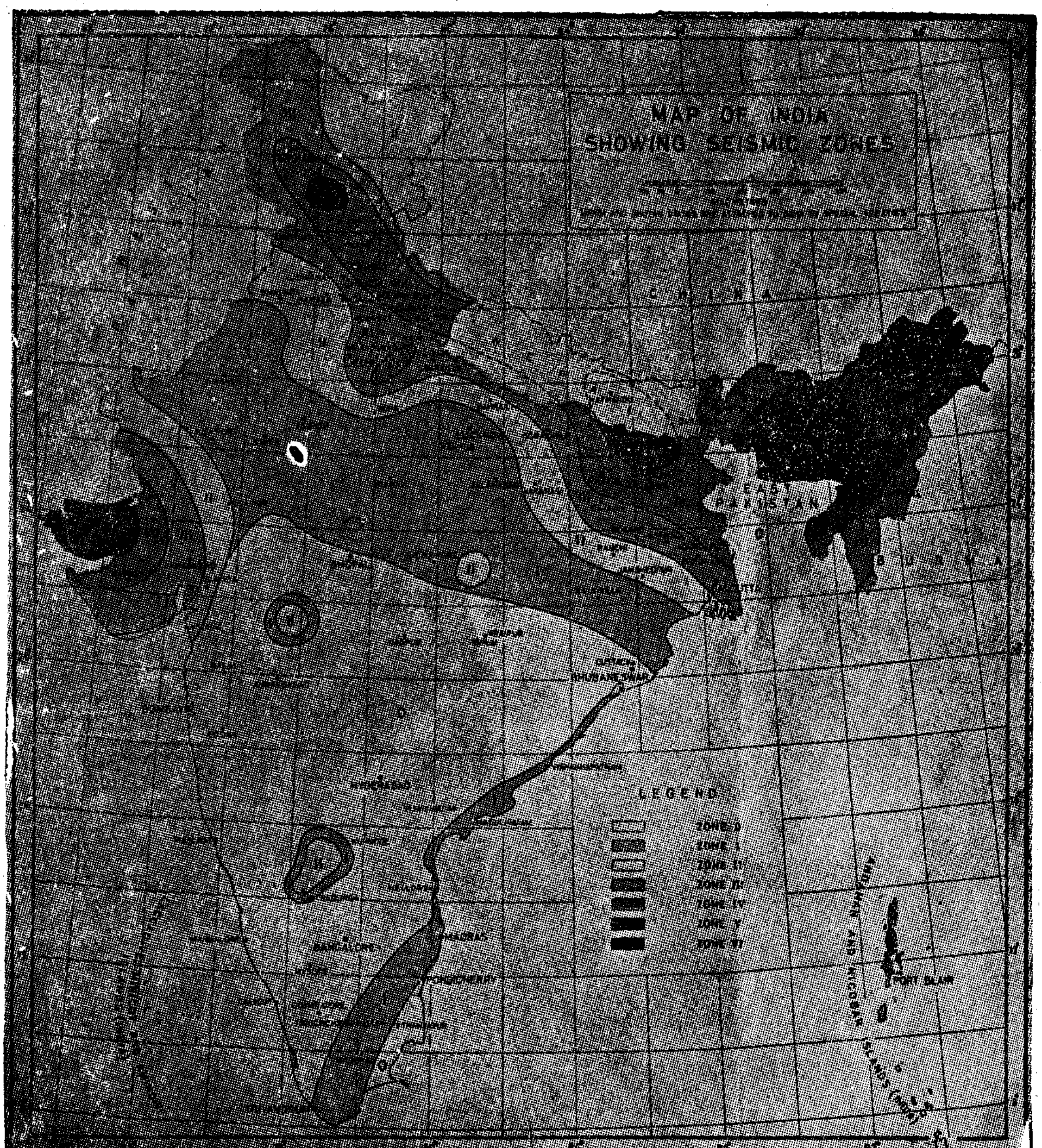

Fig. 1 Map of India Showing Seismic Zones as per IS:1897-1962

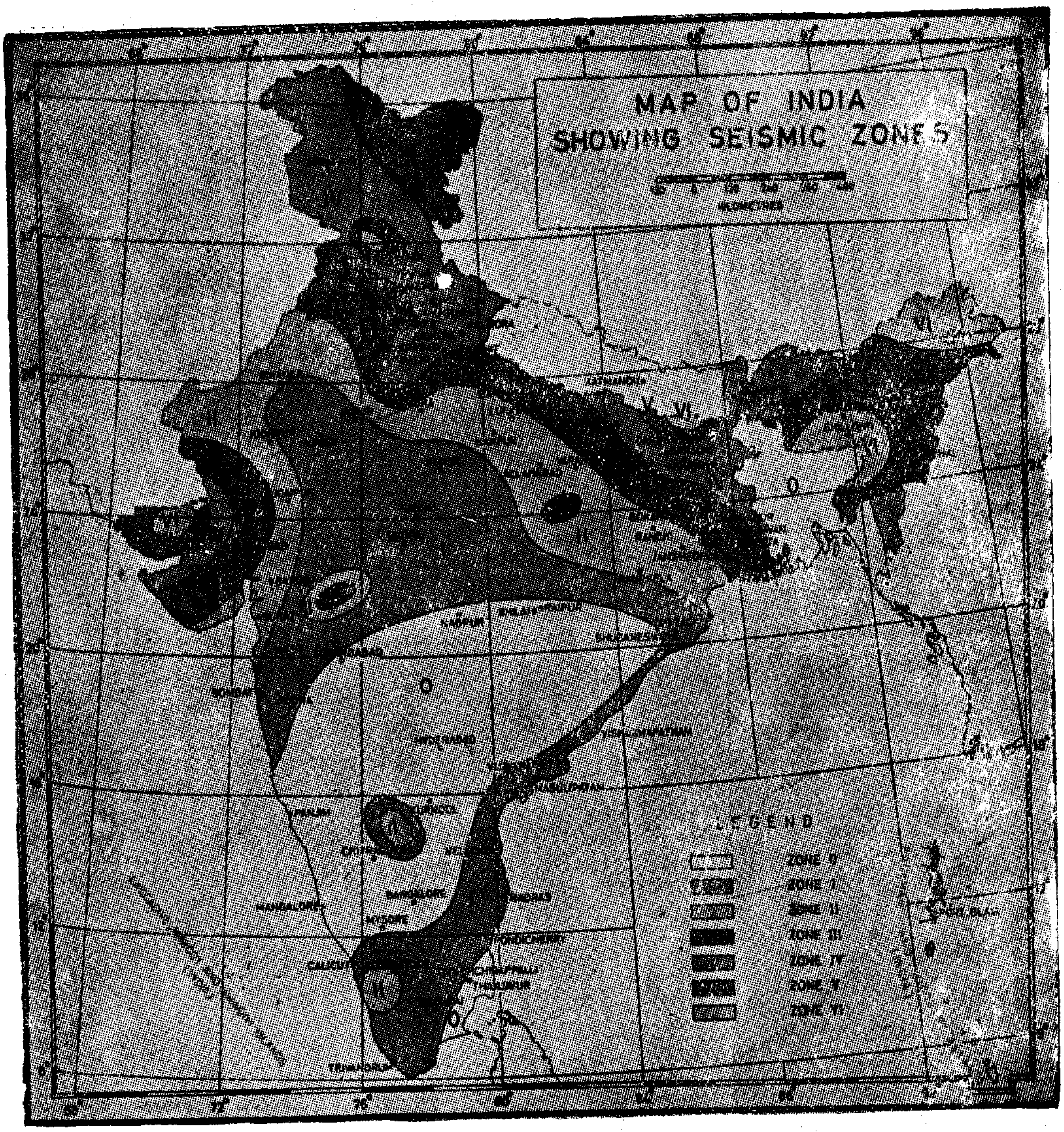

Fig. 2 Map of India Showing Seismic Zones as per IS:1897–1966.

was enhanced from zone III to zone IV in recognition of the activity related to the Himalayan thrusts, which has shown higher seismicity in other parts, and in the north-east part of Kashmir from zone II to zone III. (5) In north eastern part of the country zone V was readjusted to have a better accord with new data on tectonics and earthquakes. Zone III in Manipur and Tripura region was removed as the tectonics indicated higher activity. (6) In Andaman Islands the seismis status was upgraded on earthquake data from zone V to zone VI and other lesser zones were demarcated accordingly, (7) Earthquakes in the Satpura belt were replotted on the basis of revised data and the isoseismals of the Satpura and Rewa Earthquakes were elongated in the direction of the Narbada rift as this tectonic feature was taken to be their causative lineament. These eyelets were not joined to form a single zone along the Narbada rift due to lack of evidence of earthquake occurrences in the intervening area. The area in which these earthquakes were felt indicated higher magnitude of the earthquakes and the eyelets were marked from zone I and II to zone II and III. (8) Keeping in view the modification of zones in Satpura region and straightening out of the embayment in the isoseismals in Uttar Pradesh, the limits of zone I to III in the northern and eastern part of Peninsular were redrawn as asymptotic envelopes around the higher isoseismals on magnitude-intensity-distance relationship from probable earthquake occurrences from their borders. (9) The Kutch region was given a higher seismic status as the 1819 Cutch Earthquake was of similar magnitude as other great earthquakes of the country and zone VI was added. The trend of the zones was elongated in east-west-direction following the major faults. (10) In Gujarat region the sudden discountiuity from seismic zone II to seismic zone 0 east of Baroda and Surat was removed; and based on the tectonic set-up and occurrence of earthquakes in the region it was considered desirable to indicate the seismogenic nature of the western coast. However, as considerable data on earthquake occurrence along the entire coast line were not available, the probable marginal depression forming a mobile belt in the Maharashtra underlying the Deccan Traps was marked as zone I. (11) The causative tectonic lineaments related to the Bellary Earthquake were re-examined and it was considered that the same appear to be related to the Dharwarian strike and thus the isoseismals were re-oriented to correspond with the Dharwarian trend in NW–SE direction. (12) Based on the data of 1901 Coimbatore Earthquake isoseismals were drawn in Kerala and surrounding region so as to correspond to the trend of the Western Ghat, as it was felt that they are probably related to the seismogenic faulted western coast and related lineaments. (13) The extent of zone 0 in southern part of the Peninsula was thus curtailed taking into account the modifications due to Coimbatore earthquake and minor earthquakes along the east coast region.

Revision of 1966 Seismic Zoning Map

Shortly after the publication of the 1966 Seismic Zoning Map a large earthquake occurred at Koynanagar (District Satara) at the boundary of the probable marginal depression in the Maharashtra region. This earthquake indicated that the comparatively low seismic status, which was till then considered adequate for the marginal and other parts of the Peninsular shield requires modification with greater emphasis on the geological history and tectonic features present in different areas and the seismogenic nature of mapped or hidden tectonic features there in. The general approach to be followed to give greater recognition to geologic history and tectonic features was to divide the country into various tectonic units, each having characteristic geologic and tectonic history and seismic activity. With this in view Krishnaswamy (1969) proposed that in the seismic zoning of the country it would be desirable to take into account the varying magnitude of seismic activity of the various tectonic units (Table 1), with a decreasing magnitude and frequency of earthquake occurrences, and define the seismic zones so as to be in general consonance with the areal extent of these units, with local departures, as may be considered necessary or where adequate data are not available. It was also considered desirable to reduce the number of zones from seven zones in 1966 map to five zones in the revised map, as the earthquake effects below MM Intensity VI (zone 0 and I of 1966 Map) are insignificant in terms of design, to call for separation. Likewise the zone VI of 1966 map includes M M. Intensity "X and above", and as M.M. Intensity IX encompasses destruction of well designed buildings, this separation was considered to be of little practical utility, and hence this zone could be omitted.

For evaluation of the distribution of earthquake intensity in different tectonic units data on magnitudes and focal depths was considered. Though a reasonable estimate of the magnitude of the earthquakes in various tectonic units can be had, little reliable information, is available on focal depths, and it is difficult to establish definite associations of earthquake occurrences with the tectonic features. Thus the delineation of the various tectonic feature as originating or causasive lineaments, movements along which could produce earthquakes, is mostly tentative, till the movements and crustal deformations along them can be confirmed by actual measurements by geodimeters, tiltmeters and other suitable instruments. Thus for the present the probable seismic intensities around the various tectonic features can be arrived at from known seismic data and assuming continuous and similar activity in homologous and adjacent tectonic features in other parts. The following describes in brief the earthquake intensies and delineation of the seismic zones (figure 3) in the various tectonic units.

1. Orogenic Unit—The regian east of Longitude 90° East consisting of Assam Himalayas, Belt of Schupen, Brahamputra valley, Shillong plateau, Mizo Hills, Tripura and other parts has shown the maximum earthquake activity in the country, and the intensities observed in various parts likely to occur in future are M. M. intensity "IX and above". The whole region thus has been kept as seismic zone V, though the tectonic features show dissimilarities with each other, and homologous and comparable tectonic features in other parts of the country show different seismic activity. This higher seismic status for this region is considered justified on the basis of the seismic data. Zone IV shown in 1966 map in the Mizo Hills and Tripura Region has been removed and the area has been included in zone V.

In the Kashmir, Himachal Pradesh. Uttar Pradesh and Bihar Himalayas a number of eyelets of M.M. Intensity" IX and bove" corresponding to zone V have been marked. Though these probably could form parts of a linearly elongated belt of higher seismicity related to the Himalayan thrusts and their extensions towards north along the dips, the marked comparatively less pronounced earthquake activity in the intervening regions and lack of data, inhibit marking the whole belt as zone V. Thus tentatively four centres of of higher activity, with M.M. intensity "IX and above", have been delineated-region surrounding Srinagar with major earthquakes probably related to the down-dip extension of the Panjal thrust, the epicentral tract of the 1905 Kangra Earthquake around Dharamshala related with the downward extension of the Satlitta thrust, the area near Pithoragarh and West Nepal boundary with major earthquakes with possible associations with downward extension of the Central Himalayan thrust and other thrusts in the outer Himalayas, and area of the epicentral tract of the 1934 Bihar-Nepal Earthquake. The Srinagar and Pithoragarh zones were not demarcated in 1966 map and are new zones. In view of the presence of Karewa lake sediments in the Kashmir valley and as earthquake of magnitude 7 have occurred in the past a higher zone in Srinagar is considered justified. Similarly the Pithoragarh region, where major shocks have occurred recently, demarcation of zone V is also considered justified. The north-eastern part of Kashmir was delineated as zone III in the 1966 map, but as this region shows numerous hot springs which may be related to active faults, and as the adjacent region in the USSR and Tibet show higher earthquake activity, the seismic status of this region has been enhanced to zone IV.

TABLE NO. 1

Generalised Tectonic Units of India with Decreasing Magnitude and Frequency of Earthquake Occurrences (After V. S. Krishnaswamy, 1969)

Tectonic Unit		Earthquake Occurrence	Seismi Zones
Name	Description		
Orogenic Unit	Orogenic unit of Cainozoic folding and faulting. The Shillong massif, which has been greatly affected by this faulting, has been included in this zone.	Common shocks of mag 5–6·5 with a number of shocks of mag 6.5-7·5 a few shocks of mag 7.5-8 and occassional shocks greater than 8 originating on some of the major Himalayan thrust and faults (Sat-litta thrust, Panjal thrust, Central Himalayan thrust, Dauki faults etc.)	V and I
Foredeep and Marginal depression Unit.	Unit of Himalayan Foredeep and Marginal depression (where the boundary is not positively established, some of the marginal parts of the Shield may really be included in this zone. The Tectonic Map provisionally defines the boundary at 200 to 1000 m. contour of the basement at margin of the Shield).	Common shocks of mag 5-6 which a few shocks of mag 6-7 and occassional shocks of mag 7.5-8 originating along active faults in the basement (Patna fault ? or other basement faults, Kutch faults).	IV & II will islet of V.
West Coast & Narbada Tapti Unit.	Unit of Shield with Tertiary-Quarternary fault movemet including the West Coast seismogenic zone, the Narmada-Son rift zone, the Tapti rift zone and their postulated extensions.	Common shocks of mag 5-6 with few shocks of mag 6–7 in the Narmada and Tapti rifts. Past epicentres can be related to extensions of partly mapped faults. Maximum recorded mag. on West Coast Zone : 6.6-7, on Narbada rift 6.5, Tapti rift 6.25.	III with islets of IV.
Gondwana Rifts Unit.	Unit of Shield with Mesozoic fault movements and later adjustments, includes the Gondwana rift zone and adjacent parts of the Shield, marginal parts of the Peninsular Shield to the east and north with platform cover of Mesozoic Cainozoic sediments.	Occassional shocks of mag 5-6 with few centres which may have mag 6-6.5 and may be related to the boundary faults of the Gondwana basin and faults of limited extent in the Mesozoic-Cainozoic cover on the platform.	III
Shield Unit.	Generally aseismogenic and partitioned areas of the Peninsular Shield with ancient faults and with localised seismogenic features.	Occassional shocks of mag 5-6 with exceptional activity along local faults in the Archaeans with mag 6-6.5.	I and II with islests of III.

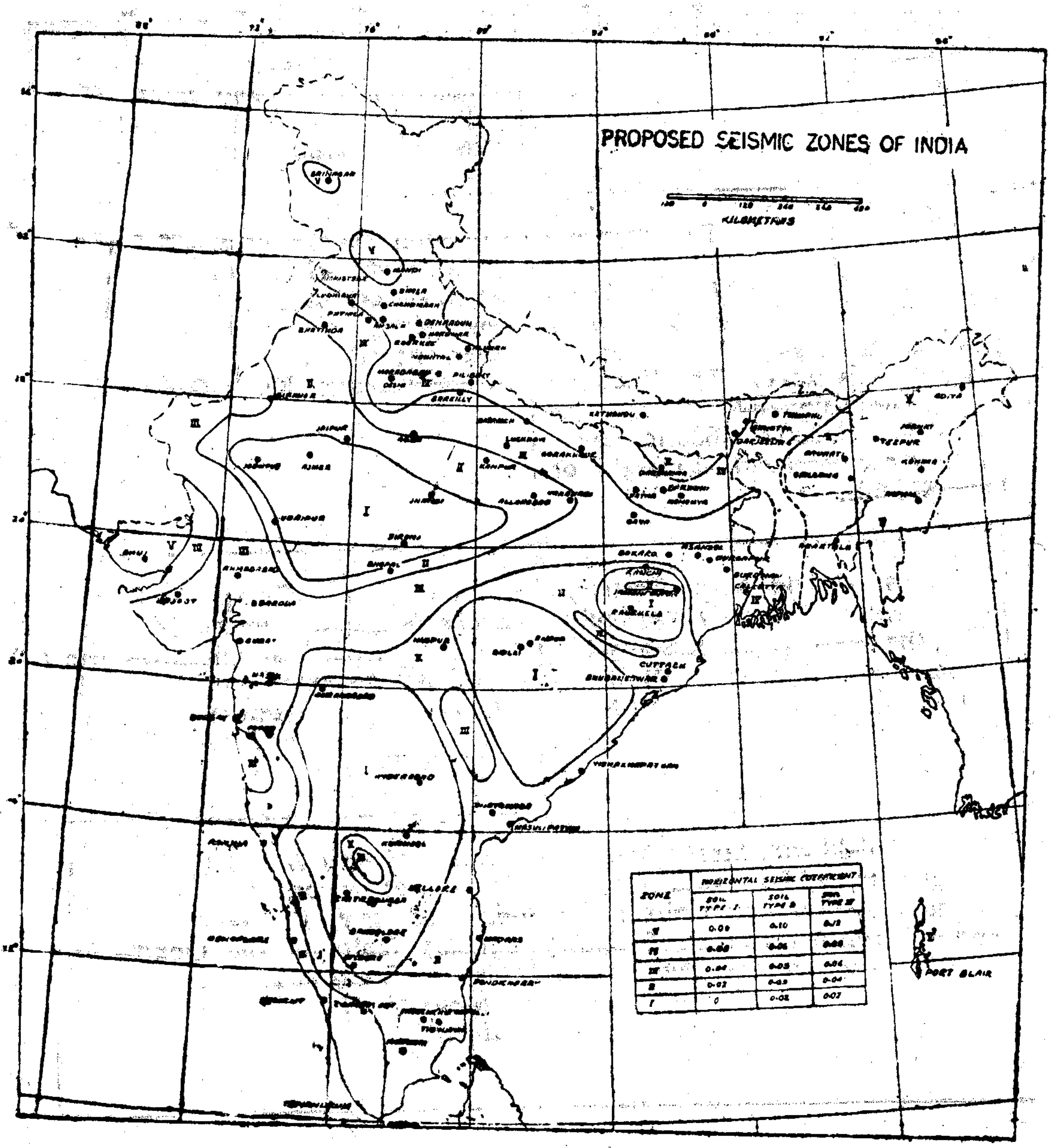

Fig. 3. Proposed Seismic Zones of India.

The Andaman-Nicobar islands, which form part of the Orogenic Unit, has been rated as zone V, and the various zones made earlier on magnitude-intensity-distance relationship have been removed as the whole belt shows similar seismic potentialities.

2. *Foredeep and Marginal Depression Unit*—In the fordeep paralleling the Himalaya and the marginal depression of the Peninsula which feel the effects of the large earthquakes emanating in the orogenic unit as well as earthquake originating along its edges and the basement faults, the boundaries of the M.M. Intensity VIII and VII were redemarcated such that the outer boundary of seismic zone III roughly follows the boundary of the marginal depressions of the Peninsular shield and the distribution of the corresponding isoseimals of the 1934 Bihar Nepal Earthquake and the 1819 Kutch Earthquake. A new seismic zone III following the marginal depresion has been demarcated in Rajasthan in this unit.

3. *West Coast and Narbada Tapti Unit*—The Tectonic Map of India (1963) shows a marginal depression, south of Cutch-Kathiawar-Cambay region along the West Coast extending for a distance of 150 kms from the coast. This mobile belt, postulated on the basis of gravity anomalies, lies burried below the Deccan traps and its exact demarcation and trend is not fully known However, in this belt a number of earthquakes have occurred in the past and the 1967 Koyna Earthquake occurred along its postulated border with the shield. In 1966 it was considered that, though earthquakes occur in this region, the intensity of earthquakes has not exceeded M.M Intensity V and the mobile belt in this part be kept as seismic zone I. The Koyna earthquake has thus focussed the necessity of reassessment of the seismicity of this belt. The two major seismotectonic features of this belt are the West Coast Fault and the West Coast Rift. The latter has been postulated by Tipnis and Srivastava (1968) and is considered to follow the West Coast in the Deccan Trap region, with its southern extensions off-setted towards west off the coast line. The region north of Panjim thus is susceptible to a wider belt of seismogenic features. The coastal belt between Panjim and Calicut is considered to be associated with only the West Coast Fault and a narrow belt along the coast would thus be seismogenic. South of Calicut the Coimbatore Earthquake, with its epicentre about 150 kms from the coast, appears to be related to hidden faults, following the local prevalent Pre-Cambrian orogenic trend and associated with the West Coast Fault. M.M. Intensity VII has been observed in the Maharashtra and Coimbatore region and the whole coastal belt is thus considered to have potentialities to produce similar intensities. This belt therefore, is marked as seismic zone III of varying width following the coast line with an islet of seismic zode IV in the Koyna region where higher intensities have been observed. The trend of the zone IV has been aligned in NNW-SSW direction along the likely trend of the Dharwarian strike below the Deccan trap which also appears to have controlled the trend of the postulated West Coast Rift resulting from the cymatogenic warping of this part of the Peninsular shield.

The Satpura Rift system along Narbada, Son and Tapti has indicated higher seismicity and extend across the shield from Saurashtra in the west to Bihar in the east, with possible extensions in Bengal. This belt of rifts and troughs, along with the plateau in between Narbada and Tapti, which may have hidden faults in the underlying basement, is considered to have seismic potential of producing an earthquakes similar to the Satpura Earthquake all along its bounding faults and thus the region encompassing distances upto 30 kms from the bounding faults and the areas within the troughs and the plateau between the Narbada and Tapti rivers has been marked as seismic zone III. This seismic zone III has been merged towards east with the seismic zone III of the Damodar valley and that marked due to the observed effects of the 1934 Bihar-Nepal Earthquake.

4. *Gondwana Rift Unit*—In the earlier preparation of seismic zoning maps the Gondwana rifts were considered to be stable with no earthquake activity associated with them. Such as assumptions has been proved to be fallacious by the 6.5 magnitude 1969

Bhadrachalam Earthquake. A study of old records show evidences of earthquake activity along Gondwana Rifts in earlier times also. With this in view the Gondwana rifts along the Godawari, Mahanadi and Damodar valleys have been classed as regions of seismic zone III. In the Godawari and Mahanadi valleys these have been shown as elongated belts of seismic zone III and the Damodar valley has been merged with seismic zone III of Satpura belt.

5. *Shield Unit*—The delineation of the various zones along various tectonic units leaves those parts of the Peninsular India which have shown comparatively much lower seismicity. Earthquakes have been felt in its various parts, but exact correlations with known or hidden tectonic features are not known. The eastern coast of India has been marked as zone II. The region east of the Chotangpur Plateau bordering West Bengal has been kept in zone III in continuation of the Damodar rift zone and the Bengal Basin of higher seismicity. The Singhbum Copper Belt Thrust and associated thrusts have shown earthquake activity during the last several years and the region thus has been delineated as seismic zone II along this belt. The isoseismals associated with Bellary earthquake have been drawn as before, but a higher zone III has been introduced on reassesment of the effect of this earthquake. In other parts of the shield unit deliniation have been made to conform with the distribution of the seismic zones in other tectonic units and occurrence of earthquakes, which are in general are of low magnitude.

From the foregoing description it would be evident that the proposed modifications in the 1966 seismic zoining map give greater recognition to tectonic features of the various parts of the country. But as considerable amount of data on earthquake occurrences and their associated tectonic features is not available and large scale maps showing orogenic-structural-stratigraphic belts have not been prepared for many parts of the country, only tentative modifications can be adopted in the different seismic zones. The revision of the seismic zones of the country is a long term continuous process and periodical revisions can be made as more data is obtained.

Acknowledgement

The author is thankful to Dr. Jai Krishna, Professor and Director, School of Research and Training in Earthquake Eengineering University of Roorkee, Roorkee, and Chairman Earthquake Engineering Sectional Committee, BDC 39, Indian Standrds Institution, New Delhi, Shri V S. Krishnaswamy, Director (E.G. Division). Northern Region, Geological Survey of India, Lucknow, and Convener, Maps Panel BDC 39:Pl, Indian Standards Institution, New Delhi, Dr. A.N. Tandon, Deputy Director General of Observatories, India Meteorological Department, New Delhi, Dr. S K. Guha, Chief Research Offices (Earthquake Engineering), Central Water and Power Research Station, Poona, and other members of the Maps Panel for their various discussions on the preparation and revision of the seismic maps of the country, which has helped in the preparation of this paper.

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SEISMOLOGICAL NOTES

(India Meteorological Department, New Delhi)

Earthquakes in and near about India during October—June, 1969

Date	Origin time (G.M.T.) h.	m.	s.	Epicentre Lat. (°N)	Long. (°E)	Region	Appox. depth (Kms)	Magnitude	Remarks
1	2	3	4	5	6	7	8	9	10
Oct 03	15	20	48.6 (CGS)	18 3	94 8	Burma	30	4.9	
Oct 06	07	42	25 2 (CGS)	10.0	93 7	Andaman Islands	111	5.1	
Oct 10	22	49	01.5 (CGS)	37.2	70.0	Afghanistan USSR Border	33	4 9	
Oct 11	03	16	50 0 (CGS)	36.0	69 5	Hindukush	185	4.7	
Oct 12	—	—	—	—	—	—	—	—	Tremor felt at Jwala Mukhi and Dalhousie at 19h 06m GMT. Another tremor felt at Rohtak at 22h 01m GMT.
	23	20	19 3 (CGS)	36.4	70.8	Hindukush	203	5.3	
Oct 14	05	22	44.3 (CGS)	12.6	95 2	Andaman Islands	—	5.5	
Oct 15	17	47	39.0 (CGS)	6.1	95.5	Nicobar Islands	35	4 9	
Oct 15	—	—	—	—	—	—	—	—	Tremor felt at Rohtak at 23h 14m GMT.
Oct 18	18	53	12.9 (CGS)	12.3	95.1	Andaman Islands	—	4.6	
Oct 19	02	33	30.9 (CGS)	37.3	73.1	Tadzhik SSR	76	4.9	
	07	01	33.4 (CGS)	37.3	73.2	Tadzhik SSR	51	5.2	
	09	52	03.4 (CGS)	37.5	73.3	Tadzhik SSR	—	5.4	
Oct 24	04	15	16.4 (CGS)	0.3	99.7	Northern Sumatra	—	5.1	
Oct 25	—	—	—	—	—	—	—	—	Tremors felt at Rohtak at 06h 57m GMT. 07h 47m GMT, 07h 48m GMT.
	10	29	24.1 (CGS)	4.3	95.8	Northern Sumatra	33	5.5	

1		2	3	4	5	6	7	8	9	10
Oct	28	17	48 (CGS)	29.1	27.3	86.1	Nepal	37	4.8	
Oct	29	09	59 (CGS)	59.9	17.3	73.9	Koyna	1	5.4	Felt at Poona.
		10	00 (NDI)	02.5	17.4	73.8	Do	12	5.5	Felt at Bombay, Poona and Panaji
Oct	30	04	07 (CGS)	20.7	37.4	73.2	Tadzhik SSR	12	5.5	
	—	—	—	—	—	—	—	—	2.8 (NDI)	Tremor felt at Rohtak at 11h 00m GMT
Nov	01	20	49 (CGS)	17.3	37.6	72.2	Tadzhik SSR	41	4.7	
Nov	02	—	—	—	—	—	—	—	—	Termor felt at Rohtak at 15h 50m GMT
Nov	04	08	18 (NDI)	18.5	16.2	74.0	Savantvadi, Maharashtra State	20	3.5	Felt at Savantvadi, with sound preceding
		09	02 (CGS)	31.8	12.2	58.0	Arabian Sea	—	5.1	
Nov	05	02	02 (NDI)	42.5	32.4	76.3	Himachal Pradesh	30	4.8	Felt at Kotla near Kangra
		02	02 (CGS)	44.2	32.4	76.4	Himachal Pradesh	—	4.9	
		03	07 (CGS)	08.3	32.4	76.6	Himachal Pradesh	—	—	
		03	07 (NDI)	08 8	32.1	76.1	Himachal Pradesh	28	4.5	Felt at Kotla near Kangra
Nov	09	13	43 (CGS)	38.4	23.8	64.7	Near coast of West Pakistan	—	5.3	
		13	43 (NDI)	40.0	24.0	65.0	Arabian Sea	—	5.8	
Nov	18	05	05 (CGS)	04.3	33.1	71.1	West Pakistan	41	5.3	
		08	49 (CGS)	07.6	26.8	92.3	Eastern India	72	4.0	
Nov	19	22	48 (CGS)	03.9	8.7	94.1	Nicobar Islands	—	4.9	
Nov	21	03	04 (CGS)	39.0	36.4	70.6	Hindukush	204	5.0	Felt at Dushanbe, Tadzhik SSR
Nov	23	—	—	—	—	—	—	—	—	Tremor felt at Shillong at 00h 52m GMT
Nov	23	—	—	—	—	—	—	—	—	Tremor felt at Rohtak at 06h 28m GMT

1	2	3	4	5	6	7	8	9	10
Dec 01	01	11 (CGS)	16.0	36.7	71.3	Afghanistan-USSR Border	144	4.8	
Dec 02	—	—	—	—	—	—	—	—	Tremor felt at Sonepat at 16h 52m GMT
Dec 05	09	01 (CGS)	26.4	5.1	95.8	Northern Sumatra	—	4.8	
Dec 05	—	—	—	—	—	—	—	4.5 (NDI)	Tremor felt at Poona at 22h 53m GMT
Dec 08	18	36 (CGS)	42.7	36.5	71.0	Afghanistan-USSR Border	187	4.8	
Dec 16	00	29 (CGS)	30.1	36.0	71.0	Afghanistan-USSR Border	103	5.0	
Dec 18	—	—	—	—	—	—	—	1.9 (NDI)	Tremor felt at Delhi at 20h 34m GMT
Dec 19	05	17 (NDI)	50	36.0	70.0	Hindukush	150		Tremor felt at Delhi, Rawalpindi, Peshawar and other parts of West Pakistan
	05	17 (CGS)	51.6	36.1	70.1	Hindukush	151	5.4	Felt at Kabul
Dec 20	23	37 (CGS)	56.2	36.4	71.0	Afghanistan-USSR Border	197	4.7	
Dec 23	23	20 (CGS)	00.4	36.4	70.6	Hindukush	225	4.7	
Dec 27	14	38	11.6	24.1	91.6	India-East Pakistan Border	26	5.2	Felt at Shillong
Jan 05	02	38 (CGS)	51.8	39.9	75.8	Southern Sinkiang China Province,	—	4.8 (CGS)	
Jan 05	09	56 (CGS)	41.1	28.0	85.2	Nepal	—	—	
	09	56 (NDI)	47	—	—	Nepal	—	—	Felt at Kathmandu
Jan 05	18	51 (CGS)	23.3	26.6	96.7	Burma	53	—	
Jan 08	06	03 (CGS)	16.5	17.4	60.3	Arabian Sea	33	4.7 (CGS)	
Jan 09	07	45 (CGS)	02.9	38.2	74.0	Tadzik-Sinkiang Border	137	5.0 (CGS)	
Jan 21	14	37 (CGS)	15.1	38.3	69.7	Tadzik SSR	52	5.1 (CGS)	
Jan 22	04	16 (CGS)	11.9	35.7	70.0	Hindukush	141	4.3 (CGS)	

1	2	3	4	5	6	7	8	9	10
Jan 22	19	42 (CGS)	21.8	32.2	70.0	West Pakistan	41	4.7 (CGS)	
Jan 23	20	01 (CGS)	19.6	32.2	76.1	Kashmir	—	4.0 (CGS)	Three slight earthquakes felt at Nurpur and Dharamshala at 13h 17m, 20h 01m and 23h 46m GMT
Jan 25	23	34 (CGS)	28.4	22.9	92.3	India-East Pakistan Border	50	5.2 (CGS)	
	23	34 (NDI)	37	23.5	91.6	India-Pakistan Border	—	4.7 (NDI)	Felt at Shillong
Jan 26	09	59 (CGS	12.1	38.2	73.8	Tadzik-Sinkiang Border	138	5.1 (CGS)	
	09	59 (NDI)	18.0	—	—	—	—	5.8 (CGS)	
Jan 27	09	59 (CGS)	27.2	37.3	71.5	Afghanistan-USSR Border	49	5.2 (CGS)	
Feb 04	22	00 (NDI)	39.9	29.0	76.6	60 km NW of Delhi	—	3.8 (NDI)	Felt at Delhi and neighbouring areas
Feb 07	09	25 (CGS)	38.8	27.6	94.0	Eastern India		—	
Feb 10	07	16 (CGS)	12.9	2.1	96.8	Northern Sumatra	—	5.4 (CGS)	
Feb 13	11	11 (CGS)	25.5	25.0	62.9	West Pakistan	—	5.2 (CGS)	
Feb 18	21	03 (CGS)	37.6	24.5	95.4	Burma	160	5.0 (CGS)	
Feb 22	20	37 (CGS)	07.1	26.6	92.4	Eastern India	52	4.8 (CGS)	
	20	36 (NDI)	57	26.8	93.0	Assam, India	—	5.0 (CGS)	
Mar 03	06	20 (CGS)	21.8	30.2	79.9	Tibet-India Border	20	5.3 (CGS)	
	06	20 (NDI)	22	30	80	Uttar Pradesh	—	5.2 (NDI)	Felt in Ranikhet
Mar 03	14	03 (CGS)	00.5	31.0	71.8	West Pakistan	—	4.5 (CGS)	
Mar 05	11	15 (CGS)	00.6	29.2	81.1	Nepal	63	5.2 (CGS)	
	11	15 (NDI)	01	—	—	—	—	4.5 (CGS)	
Mar 05	19	33 (CGS)	23.0	36.4	70.7	Hindukush	208	5.9 (CGS)	Felt at Kabul

1	2	3	4	5	6	7	8	9	10
Mar 05	19	33	20 (SHL)	37	70	Hindukush	—	6.6 (NDI)	Felt strongly in Srinagar People woke up and ran out-doors
Mar 07	09	27	35.5 (CGS)	36.4	71.0	Afghanistan-USSR Border	195	—	
Mar 10	18	50	52.5 (CGS)	37.1	71.6	Afghanistan-USSR Border	142	4.4 (CGS)	
Mar 10	19	04	02.9 (CGS)	36.4	71.0	Afghanistan-USSR Border	201	5.1 (CGS)	Felt at Kabul
Mar 22	04	52	32.6 (CGS)	38.9	70.6	Afganistan-USSR Border	8	5.3 (CGS)	
Mar 23	04	21	31.4 (CGS)	24.4	68.7	India-Pakistan Border	15	4.4 (CGS)	
Mar 26	18	00	54 (NDI)	22.6	78.1	Near Itarsi, Madhya Pradesh	—	4.2 (NDI)	
Mar 27	11	19	29.3 (CGS)	39.0	71.9	Tadzik, SSR	37	4.9 (CGS)	
Mar 27	27	19	44.1 (CGS)	39.0	71.8	Tadzik, SSR	—	5.2 (CGS)	
April 01	05	49	07.5 (CGS)	36.3	70.8	Hindukush	212	4.6 (CGS)	
April 01	16	36	23.4 (CGS)	30.0	67.4	West Pakistan	20	4.9 (CGS)	
April 02	12	36	38.2 (CGS)	8.7	93.9	Nicobar Island	—	4.5 (CGS)	
April 03	00	03	20.9 (CGS)	37.1	71.8	Afganistan-USSR Border	155	—	
April 12	22	18	09.7 (CGS)	36.2	69.7	Hindukush	119	4.0 (CGS)	
April 13	15	24	55 (NDI)	17.6	80.6	Near Bhadra-chalam, Andhra Pradesh,		6.5 (NDI)	One of the most significant Earthquakes in Peninsular India.
	15	24	55.6 (CGS)	17.9	08.6	India	—	5.7 (CGS)	Felt over a wide area; slight damage to old structures.
April 14	17	58	39 (NDI)	18	80.1/2	Andhra Pradesh	—	6.0 (NDI)	Aftershock of the Earthquake of 13th April, 1960.
April 14	18	07	11.4 (CGS)	36.1	71.0	Afganistan-USSR Border	147	4.5 (CGS)	
April 17	03	21	16.4 (CGS)	30.1	69.9	West Pakistan	7	4.5 (CGS)	
April 22	09	06	58.5 (CGS)	23.2	92.7	India-East Pak. Border	39	—	
April 25	04	52	58.4 (CGS)	5.0	97.9	Northern Sumatra	—	4.9 (CGS)	
April 25	07	36	36.2 (CGS)	30.8	70.3	West Pakistan	23	4.9 (CGS)	

1	2	3	4	5	6	7	8	9	10
April 28	12	50 (NDI)	22	25	93.5	Manipur Burma Border	—	—	
	12	50 (CGS)	15.2	25.9	95.3	Burma-India Border	50	5.2 (CGS)	
April 29	09	35 (CGS)	25.1	35.7	70.2	Hindukush	189	4.7 (CGS)	
April 30	16	34 (CGS)	44.9	8.2	93.0	Nicobar Island	—	5.0 (CGS)	
May 03	13	23 (NDI)	35	23.0	86.6	Near Bankura, W. Bengal	—	5.7 (NDI)	Felt at Calcutta and other parts of West Bengal
May 04	03	22 (CGS)	03.7	36.4	71.5	Afganistan-USSR Border	126	4.6 (CGS)	
May 04	04	28 (NDI)	21.5			22kms West of Delhi	—	2.8 (NDI)	Felt at Delhi
May 04	20	56 (NDI)	44.5			22kms From Delhi	—	—	Felt at Delhi
May 08	02	31 (NDI)	14.3	28.8	76.6	Near Delhi	—	3.4 (NDI)	Felt at Rohtak
May 08	17	49 (CGS)	51.7	31.1	72.3	Tadzik SSR	—	—	
May 10	13	07 (CGS)	30.4	36.2	71.4	Afganistan-USSR Border	161	—	
May 11	13	16 (CGS)	32.7	36.2	71.3	Afganistan-USSR Border	110	4.5 (CGS)	
May 12	10	04 (CGS)	38.6	39.9	70.9	Tadzik SSR	—	4.8 (CGS)	
May 13	12	27 (CGS)	51.7	38.0	73.4	Tadzik Sinkiang Border	211/1	4.6 (CGS)	
May 19	08	46 (NDI)	02			320kms NW of Delhi Himachal Pradesh	—	3.8 (NDI)	Felt at Sundernagar
May 19	10	01 (CGS)	47.8	36.1	71.3	Afganistan-USSR Border	141	4.6 (CGS)	
May 20	00	41 (NDI)	37	28.7	76.7	Near Delhi	—	2.0	
May 23	17	07 (CGS)	42.2	3.7	95.7	Coast of N. Sumatra	47	5.2 (CGS)	
May 31	15	27 (NDI)	40	29.1	76.6	Near Rohtak, Hariana	—	4.0 (NDI)	Felt in Delhi, Sonepat and Rohtak.
May 31	21	59 (CGS)	41.9	36.3	70.9	Hindukush	134	4.7	
June 01	08	35 (NDI)	25	26	91	40 km from Shillong	—	5.6 (NDI)	
	08	35 (CGS)	22.1	25.8	91.8	India East-Pakistan Border	20	5.0 (CGS)	

1		2	3	4	5	6	7	8	9	10
June	01	08	35 (CGS)	22.1	25.8	91.8	India East-Pakistan Border	20	5.0 (CGS)	
June	01	12	36 (CGS)	30.2	26.7	60.6	Southern Iran	50	4.7	
June	02	17	53 (CGS)	04.5	36.3	71.2	Afganistan-USSR Border	228	4.8 (CGS)	
June	03	10	19 (CGS)	15.9	6.7	94.8	Nicobar Islands	—	4.5 (CGS)	
June	04	16	21 (CGS)	34.7	25.6	61.1	Southern Iran	—	4.7 (CGS)	
June	05	06	09 (CGS)	28.5	36.7	71.2	Afganistan-USSR Border	232	4.6 (CGS)	
June	05	10	45 (CGS)	43.5	4.9	96.3	Northern Sumartra	—	5.3 (CGS)	
June	10	22	52 (NDI)	15	35	70.5	Hindukush	—	5 9 (NDI)	
		22	52 (CGS)	12.1	36.4	70.7	Hindukush	230	5.4 (CGS)	
June	10	23	30 (CGS)	53.7	36.3	70.4	Hindukush	213	5.2 (CGS)	
June	11	04	48 (CGS)	20.3	1.1	98.8	Northern Sumatra	53	5.3	
June	14	03	28 (CGS)	29.6	31·7	94.6	Tibet	—	5.3 (CGS)	
June	18	17	11 (CGS)	48.0	1.6	66.7	Carlsberg Ridge	23	5.0 (CGS)	
June	18	20	08 (CGS)	36.4	5.9	94.7	Northern Sumatra	69	5.1 (CGS)	
June	19	18	18 (CGS)	59.8	38.5	71.0	Afganistan-USSR Borders	117	4.8 (CGS)	
June	21	17	32 (CGS)	56.6	35.6	81.9	S. Sinkiang, China	—	4.5 (CGS)	
June	22	01	33 (NDI)	24	30.8	79.3	Near Kedarnath	—	5.8 (NDI)	Felt at Chandigarh, Ambala, Mussoorie, Dehradun, Hardwar, Roorkee, Saharanpur.
		01	33 (CGS)	24.1	30.6	79.4	Tibet India border	19	5.4 (CGS)	Felt in Southern and Central Punjab.
June	25	07	24 (CGS)	49.4	4.5	96.7	Northern Sumatra	—	5.3 (CGS)	
June	27	Two slight earthquakes in Koyna Region at 20h 05m 10E sec and 20h 05m 25s.								
June	29	12	44 (CGS)	04.6	36.3	70.6	Hindukush	223	4.8 (CGS)	
June	30	08	52 (NDI)	02	120km North East of shillong			—	5.2 (NDI)	
		08	51 (CGS)	56.7	26.9	92.6	Eastern India	64	5.1 (CGS)	

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SECRETARY'S REPORT ON THE WORK OF THE SOCIETY FOR THE PERIOD 15-12-1968 TO 22-12-1969

1. **Five meetings of the Executive Committee were held during the year at Roorkee and New Delhi.**

2. **Fourth world Conference on Earthquake Engineering.**

The IV WCEE was held in Santiago, Chile, from Jan. 13-18, 1969. Dr. Jai Krishna and Dr. Y.C. Das participated in this conference and represented the Society.

3. **Affiliation of Indian Society of Earthquake Technology with International Association of Earthquake Engineering.**

The International Association of Earthquake Engineering was requested to formally recognise the Indian Society of Earthquake Technology as the official body representing the interests of Engineers and Scientists in India interested in Earthquake Technology. The International Association of Earthquake Engineering has formally accepted our position as the official body.

4. **Fifth World Conference on Earthquake Engineering.**

The 5th WCEE shall be organised by IAEE in 1972-73. Your Society jointly with Institution of Engineers (India) has extended an invitation to IAEE to hold their next World Conference in India. Their acceptance for our invitation is awaited.

5. **Amendment to Constitution.**

Our constitution did not provide for Indian National Committee on Earthquake Engineering. An amendment to the Constitution was, therefore, put to vote by postal ballot as a result of which the constitution was amended and provisions for formation of an Indian National Committee on Earthquake Engineering have been made.

6. **Publications.**

The following publications of the Society were issued :

(a) Bulletins Vol. VI No. 1, 2, 3, 4 (1669) (b) Amended Constitution of the Society.

7. **Membership.**

The total membership was as under :

As on	Institution Members	Life Members	Individual Members
1-12-1968	21	21	214
1-12-1969	24	32	195

All the members have been assigned a number for easy reference.

8. **Establishment of Exchange Relations.**

The Society had established exchange relationship with the New Zealand Society of Earthquake Engineering for exchange of publications of the two Societies. The relationship was strengthened during the year under report.

9. **Election of Members of the Executive Committee.**

As per the constitution of the Society, the working of the Society is governed by the Executive Committee elected for the period of one year. The term of the present Executive

Committee shall expire on 31-3-1970. The following is the composition of the Executive Committee for the year 1969-70.

1.	Sri P.M. Mane	... President
2.	Dr. Jai Krishna	... Vice-President
3.	Dr. Shamsher Prakash	... Secretary and Treasurer
4.	Sri L.S. Srivastava	... Editor
5.	Dr. A.S. Arya	... Member
6.	Dr. A.N. Tandon	... Member
7.	Dr. R.S. Mithal	... Member
8.	Dr. A.R. Chandrasekaran	... Member
9.	Dr. Jagdish Narain	... Member
10.	Dr. Hari Narain	... Member
11.	Sri S.N. Gupta, Secretary, C.B.I. & P., New Delhi	... Member
12.	Lt. Col. T.J. Tolani Army Headquarters, New Delhi	... Member

Sri J.G. Bodhe has been coopted as a member of the Executive Committee.

10. Funds.

The main source of income of the Society is the membership subscription from Institution Members, and Individual Members. The income is just sufficient to print only four issues of the Bulletin in its present form. Attempts were made to obtain grant-in-aid from the Govt. of India, but the out come was not encouraging.

11. Accounts

The accounts of the Society for the year 1967-68 have been audited by M/s Goswamy and Co., Chartered Accountants, Saharanpur. The statement of audited accounts as prepared and submitted by the auditors is given on the following page.

Shamsher Prakash

Secretary

BALANCE SHEET AS AT 31st MARCH, 1969.

LIABILTIES & FUNDS			PROPERTY & ASSEST		
Capital Fund:			*Furniture at Cost* :		26.40
Balance as per last Balance Sheet:	9,757.15		*Stock of Bulletins* (As taken, valued and certified by the Secretary valued at cost) :		3,376.77
Add Life membership subscription Capitalised:	1,016.00		*Subscription Outstanding* :		5,888.69
Fixed Deposit of previous year not taken in Account previously:	1,000.00		*Bills Outstanding* :		1,431.20
Excess of Income over Expenditure for the year ending 31-3-69:	3,194.94	14,968.09	*Suspense A/C* :		15.00
			Cash and Other Balances :		
LIABILITIES FOR EXPENSES:			Cash in hand :	11.83	
Bank Discrepancies;		165.00	Postage Stamps in hand :	1.16	
(As per last Balance Sheet):		41.38	Balance with State Bank of India in Current Account :	1,485.32	
SUBSCRIPTION RECEIVED IN ADVANCE:			Fixed Deposit Account :	3,666.00	5,164.31
Institution Members:	150.00				
Individual Members:	50.00				
Bulletin:	527.90	727.90		Total Rs.	15,902.37
Total	Rs.	15,902.37			

PROFIT & LOSS ACCOUNT FOR THE YEAR ENDING 31st MARCH, 1969.

To Opening Stock :	2,516.16		By Membership subscription (including subscription outstanding for the year) :		
,, Printing charges of Bulletins :	3,465.95		Individual Members :	3,338.69	
	5,982.10		Institution Members :	2,325.00	
Less : Closing Stock as on 31-3-69 :	3,376.77	2,605.33	Life Members Subscription :	792.00	6,455.69
,, Salary and Wages :		462.00	,, Sale of Bulletin :		1,081.50
,, Postage, Telegrams and Telephones :		1,042.65	,, Subscription of Bulletin :		310.65
,, Printing and Stationery :		350.53	,, Interest :		181.26
,, Contingency :		102.05		Total Rs.	8,029.10
,, General Meeting expenses :		154.60			
,, Audit fee :		75.00			
,, Bank charges :		42.00			
,, Surplus carried over to Capital Fund in the Balance Sheet :		3,194.94			
	Total Rs.	8,029.10			