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Seismic Hazard Analysis with Moment Release Constraint in Upper Himalayas Region: An Overview

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Abstract : *Probabilistic Seismic Hazard Analysis (PSHA) Characterizes Ground Motion Hazard From Earthquake. PSHA Analysis Is Conducted Where There Is A Perceived Earthquake Threat From Active Seismic Source In The Region That May Produce A Large Earthquake. These Earthquakes Occur During The Years To Decades Prior To The Occurrence Of The Large Event And Over A Region Larger Than Its Rupture Zone. The Size Of The Region In Which These Earthquakes Occurs Scales With The Size Of The Ensuing Foreshock Or Main-Shocks, At Least In Continental Regions. A Number Of Numerical Simulation Studies Of Faults And Fault Systems Also Exhibit Similar Behavior. The Combined Observational And Simulation Evidence Suggests That The Period Of Increased Moment Released In Earthquakes Signals The Establishment Of Long Wavelength Correlations In The Regional Stress Field. This Paper Presents A Brief Overview Of Seismic Hazard Analysis Method And A Peak Into Various Seismic Zones In Which Our Study Area Is Divided Based On Seismotectonic Segments. The Main Aim Of This Study Is To Review The Work Already Done Till Now On The PSHA Analysis.*
Keywords –*Earthquake, Foreshock, Probabilistic Seismic Hazard Analysis, Seismotectonic, Wavelength.*

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I. INTRODUCTION

Seismic Hazard Is The Characterization Of Various Natural Effects Of Earthquakes Occurrence That Have Enough Potential To Cause Loss Of Life And Property. Seismic Hazard Is Determined From Historical, Geological And Instrumental Observations And It Occurs Naturally Without Any Control Over It. Hazard Analysis Should Consider All Uncertainties In Input Data And Parameters To Have High Confidence In The Estimated Hazard Levels.

The Seismic Hazard Analysis Deals With The Evaluation Of The Levels Of Various Natural Effects Of Earthquakes. Several Parameters Are Used For Measurement Of Seismic Hazard Like Peak Ground Acceleration [1], Surface Faulting, Soil Liquefaction And Peak Strains.

Basically Seismic Hazard Can Be Represented Most Frequently In Terms Of Probability Of Peak Accelerations, Peak Velocities, Peak Displacements Or The Complete Response Spectrum. Two Approaches Are Commonly Used For Determining Seismic Hazard, Namely:

i) Probabilistic Seismic Hazard Analysis (PSHA)
ii) Deterministic Seismic Hazard Analysis (DSHA)

The Latest Version Of Seismic Zoning Map Of India Given In The Earthquake Resistant Design Code Of India [IS 1893(Part 1) 2002] Assigns Four Levels Of Seismicity (Zone 2, 3, 4 And 5) For India In Terms Of Zone Factors. According To Present Zoning Map, Zone 5 Expects The Highest Level Of Seismicity Whereas Zone 2 Is Associated With The Lowest Level Of Seismicity. The Seismic Zone Map Of India Is As Shown In Fig. 1.

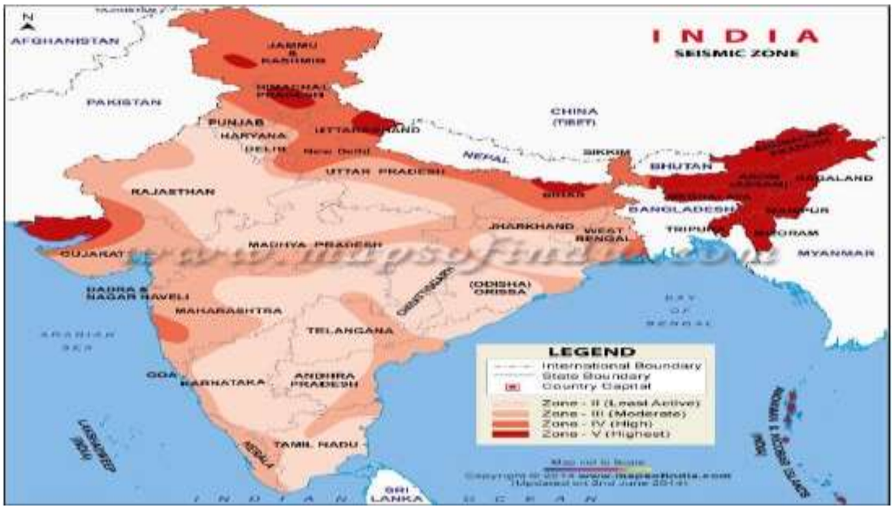

Fig.1: Seismic Zone Map OfIndia

The North Himalayan Region Lies Between Latitude 26^0N To 44^0N And Longitude 68^0E To 104^0 E. The Division Of The Studied Area Into Seismotectonic Segments, I.E Into Seismotectonically Homogeneous Parts Of Seismic Zones, Is One Of The Basic Requirements For The Application Of The Estimation Procedure For Seismic Hazard Parameters. The Himalayan Region (26^0 N - 44^0 N And 68^0 E - 104^o E) Is Seismically Very Active And Highly Complicated From Seismotectonic Point Of View, And For The Reason, The Whole Himalayan Seismic Area Has Been Divided Into Six Seismic Zones Based On Seismotectonic Segments, Seismicity Distribution And Topographic Variations. The Six Seismic Zones Along The Major Tectonic Features Of The Seismic Zone Are As Follows:

i) Seismic Zone I - Hindukush-Pamirs(HKP), (28^o-42^o N And 68^o- 75^o E)
ii) Seismic Zone II - Kashmir-Himachal Pradesh (KHP), (28^o-42^o N And 75^o-80^o E)
iii) Seismic Zone III - India-Western Nepal Border (IWNB), (28^o-36^o N And 80^o-85^o E)
iv) Seismic Zone IV - Nepal-India-Sikkim Border (NISB), (26^o-30^o N And 85^o-90^o E)
v) Seismic Zone V - North-East India (NEI), (26^o-30^o N And 90^o-95^o E)
vi) Seismic Zone VI - Burma-Andaman-Nicobar (BAN), (26^o-30^o Nand 95^o-104^0 E).

Several Studies Have Been Carried Out In The Past To Determine The Seismic Hazard In The Vicinity Of Main Central Thrust (MCT) And Main Boundary Thrust (MBT) Of Himalayan Region By Using Various Models And Hazard Analysis Method. Two Methods Namely, Deterministic Seismic Hazard Analysis (DSHA) And Probabilistic Seismic Hazard Analysis (PSHA) Are Used For Determining Hazard .This Paper Reviews The Probabilistic Analysis Of Seismic Data Of The North Himalayan Region With Seismic Moment Release Constraint. Poisson's Distributions Exponential Model, Recurrence Relation and Attenuation Relationship Are Used to Estimated Hazard.The Moment Release Rate M_0Is Used To Determine The Strength Of A Seismic Source. Therefore, It Is Necessary To Estimate The Seismic Moment Release Rate To Constraint The Scaling And Distribution Parameters (A And B Value), That Define The Recurrence Relationship For Estimating Hazard.

The Study Of The Seismo-Tectonics Of This Region Has Been Made Using Past Earthquake Data. This Earthquake Data Is Taken From Earthquake Catalogue Prepared By Various Sources Such As USGS, ISC And IMD. These Are Essential Requirements To Estimate The Seismic Hazard.

In This Study Earthquake Data Have Been Analyzed Using ZMAP Software To Determine The Source Characteristics [2]. A Broad Area Bounded By Longitudes 68^o To 104^oE And Latitudes 26^o To 42^oN Has Been Taken For The Digitization Of Tectonic Features, Plotting And Distribution Of Earthquakes Magnitude-Wise, Creation Of Seismogenic Source Zones, Zone Boundary Co-Ordinates. For This Purpose, The Software Surfer Has Been Used.

II. LITERATURE REVIEW

In The Past Few Decades, Several Studies Have Been Conducted On Probabilistic Seismic Hazard Analysis To Predict The Response Of Earthquakes, Of Which Few Of Them Are Listed Below:

Moket al[3] Monitored Distant Earthquakes Since 1921 Using Long-Period Seismographs And Established A Long-Period Seismograph Network For Monitoring Local Tremors In 1979. The Probabilistic Seismic Hazard Assessment Which Estimates Potential Seismic Ground Motions On Rock Sites In Hong Kong Was Conducted. It Was Concluded That Hong Kong Is Located In A Region Of Low To Moderate Seismicity. It Was Found That The Seismic Source Zone Model Incorporates The Seismicity Of The Region, With The

Consideration Of The Geological And Tectonic Information And The Chinese Code Source Zone Boundaries. It Was Also Found That The Calculated Range Of PGA For The Hong Kong Varies From 0.09g To 0.12g For 10% Chance Probability Being Exceeded In The Next 50 Years.

N. S. Patilet al[4] Worked On The Estimation OfPeak Ground Acceleration (PGA) For The State Of Himachal Pradesh And Adjoining Regions Using Probabilistic Seismic Hazard Analysis (PSHA) Approach. Standard Procedure Was Adopted For The Study And Peak Ground Motion Were Estimated For 10% And 2% Probability Of Exceedance In 50 Years At The Bed Rock Level, Considering The Varying And Constant B-Value For Each Source Zone. It Was Observed That The Higher PGA Values Were Obtained In The Southeast Part Considering Varying B-Values, Whereas The Region Situated Around Kaurik Fault System (KFS) Showed Higher PGA Values In Case Of Constant B-Values.

I. D. Gupta [5] Conducted A Study Using Probabilistic Seismic Hazard Analysis Approach (PSHA) To Analyze The Sensitivity Of The Uniform Hazard Response Spectra (UHRS) To Site Characteristics Defined By Local Soil And Site Geologic Conditions, And To The Source Conditions Defined By Moment Release Rate, Maximum Magnitude And Gutenberg-Richter's B Value. It Was Observed That Rather Than The Maximum Magnitude, The Moment Release Rate Defines The Strength Of A Seismic Source In An Absolute Way, And The B-Value Controls The Relative Number Of Earthquakes With Different Magnitudes. It Was Also Found That The UHRS Represents The Effects Of The Site Condition In A Realistic Way And Hence Can Be Used To Provide A Useful Basis For Estimating The Site-Specific Design Ground Motion For Practical Applications.

Sandip Das et al [6] Prepared The Seismic Hazard Maps For Northeast India Based On The Uniform Hazard Response Spectra For Absolute Acceleration At Stiff Sites. The Entire Area Of Northeast India Was Divided Into 0.1° Grid Size, And The Hazard Level Was Assessed For Each Node Of This Grid By Considering The Seismicity Within 300km Radius Around The Node. Uniform Hazard Contours For Pseudo-Spectral Acceleration As The Hazard Parameter Were Obtained For An Exposure Time Of 100 Years And For 50% Confidence Level At Different Natural Periods For Both Horizontal And Vertical Components Of Ground Motion. It Was Observed That The Trends Reflected By These Contours Were Broadly Consistent With The Major Seismotectonic Features In The Region.

R. B. S. Yadavet al[7] Studied On The Probabilistic Assessment Of Earthquake Hazard Parameters And Seismicity In 28 Seismogenic Source Zones Of NW Himalaya And The Adjoining Regions. For This Purpose, A Complete Earthquake Catalogue Was Prepared During The Period Of 1500-2010. It Was Observed That The Seismic Hazard Level Varies Spatially From One Zone To Another Which Suggests That The Examined Regions Have High Crustal Heterogeneity And Seismotectonic Complexity. It Was Also Concluded That The North West Himalaya And The Adjoining Regions Are Some Of The Most Seismically Active Regions In The Alpine-Himalayan Seismic Belt, Where Seismicity Is Mainly Related To The Ongoing Continent-Continent Collision Of The Indian And Eurasian Plates.

P. Chingthamet al[8] Conducted An Assessment Of Seismicity Parameters In The Northwest Himalaya And The Adjoining Regions Using An Earthquake Catalog From India Meteorological Department During A Period Of June 1, 1988 To June 30, 2011. The Spatial Distribution Of Seismicity Parameters, Namely Magnitude Of Completeness (M_C), A Value, B Value And Correlation Fractal Dimension (D_C), Were Estimated For The Studied Region. It Was Concluded That The Structural Heterogeneity Caused By Different Stress Accumulation And Rock Fracturing Densities Existed Due To Continuous Tectonic Adjustments Between Different Geomorphic Features Of The Studied Region.

III. PROBABILISTIC SEISMIC HAZARD ANALYSIS METHOD

The Probabilistic Seismic Hazard Analysis Approach Defines A Composite Probability Distribution Function For Any Strong-Motion Parameter Due To The Total Expected Seismicity In The Area Around The Site. Using The Occurrence Rate $Y_n$of Earthquake With Magnitude M_jAnd Distance R_iIn The N^{th} Seismic Source, The Occurrence Rate $\lambda(Z > Z)$ For A Ground Shaking Parameter Z Exceeding A Value Z Can Be Defined As A Linear Combination Of Y_n (M_j,R_i) Which Is Defined By Poisson's Distribution. So The Probability Of Parameter Z > Z Due To All The Earthquakes In All The Source Zones During A Period Of Y Years Can Be Written As:

$$\lambda(Z > z) = \sum_{n=1}^{n}\sum_{i=1}^{i}\sum_{j=1}^{j} q(Z > z \mid M_j, R_i) \times \upsilon_n(M_j, R_i) \qquad (1)$$

Using The Occurrence Rate (Z > Z), The Probability Of The Ground Motion Parameter Z Not Exceeding The Value Of Z, In Exposure Period Of Y Years Can Be Defined Under Poisson's Assumption As:

$$P(Z > z \mid Y) = 1 - \exp(-\lambda(Z > z) \times Y) \qquad (2)$$

The Reciprocal Of $\lambda(Z > z)$ Gives The Return Period T(Z > Z) Which Can Be Defined In Terms Of P (Z > Z |Y) As:

$$T(Z > z \mid Y) = 1/\ln(1 - P(Z > z \mid Y)) \qquad (3)$$

For The Estimation Of This Probability P (Z > Z| Y), PSHA Involves Following 4 Steps Which Are Illustrated In Fig. 2.

i) Identification Of Sources,
ii) Establishment Of Recurrence Relationships And Occurrence Rate For Each Source,
iii) Selection Of Attenuation Relationship,
iv) Computation Of The Site Hazard Curve.

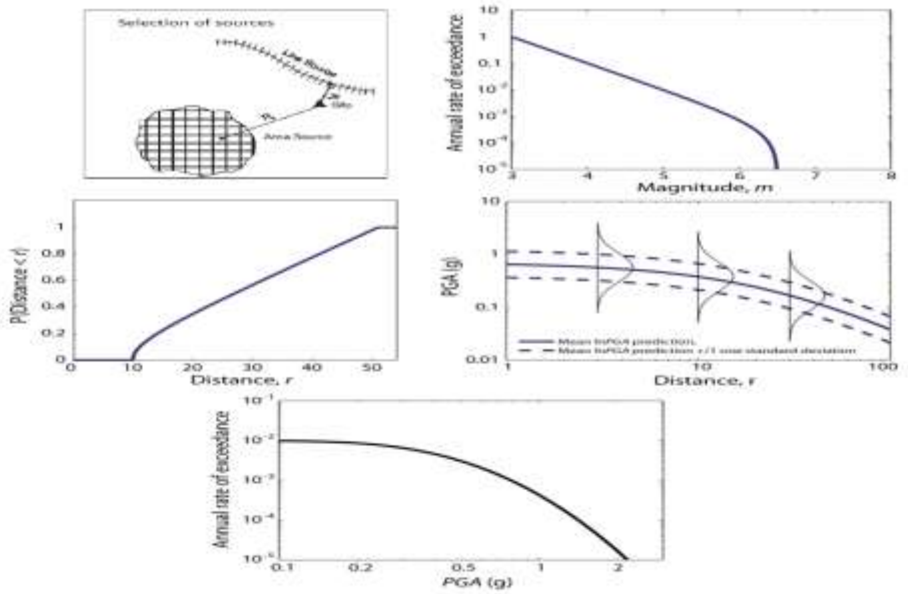

Fig. 2: Consecutive Steps For Hazard Estimation

IV. SEISMOTECTONICS AND SEISMIC SOURCES

Northern Himalayas Is High Seismicity Region. It Is Falling In Between The Seismic Gap Of 1934 Bihar–Nepal Earthquake And 1905 KangraEarthquake In The Central Himalaya Active Region.

4.1. Tectonics AndTectonic Map

The Data On Past Seismicity Shows That The Various Tectonic Features Such As Faults, Folds, Shear Zones, Lineaments, Etc. Are Most Important Components Required To Describe The Seismic Sources And Prediction Of The Future Earthquakes.The Mostly Used Tectonic Units Are Faults And Thrusts Considered For Seismic Hazard.

4.2. Earthquake Data

For The Accurate Analysis Of Seismic Hazard, A Sufficient Amount Of High Quality Data On Past Earthquakes Is Necessary. The Data Can Generally Be Taken From Earthquake Catalogues. But Many Of Existing Catalogues Are Inhomogeneous And Incomplete, So Special Care Must Be Taken To Correct These Defects In Catalogues. The Non-Instrumental And Historical Data Can Be Obtained From Catalogues Prepared By Baird-Smith [9], Oldham [10], Milne [11], Lee Et Al [12], QuittmeyerAnd Jacob [13].

The Instrumental Data Can Be Obtained From The Website Of International Seismological Centre (ISC) Http://Www.Isc.Ac.Uk/ Of UK, National Earthquake Information Center (NEIC) Of USGS Http://Earthquake.Usgs.Gov/Earthquakes/Search/, Northern California Earthquake Data Centre Http://Www.Ncedc.Org/Cnss/, And At Http://Www.Globalcmt.Org/ Under The Project Of Global Centroid-Moment-Tensor (CMT). In Addition, Catalogues Prepared By Indian Meteorological Department Can Also Be Used.

4.3. Correlation OfSeismicity With Tectonics

The Seismicity Of The Region Is Due To The Continued Convergence Of The Indian Plate Against The Eurasian Plate. Due To This Convergence Motion OfIndian Plate Towards Eurasian Plate Large Seismicity Occurs In This Zone And It Leads To The Formation Of Thrusts, I.E. The Main Central Thrust (MCT), The Main Boundary Thrust (MBT), Southern Tibetan Detachment And Main Frontal Thrust (MFT), And Several Other Thrust And Lineaments Along The Entire Himalaya.

4.4. Identification OfSeismogenic Source Zones

For The Estimation Of PSHA Of The North Himalayan Region, A Region Boundary From Latitude 26° To 44° And Longitude 68° To 104° Has To Be Selected And Earthquake Data Can Be Extracted From The

Earthquake Catalogue. After Plotting This Earthquake Data With The Tectonic Map, The Region Is To Be Divided Into Several Seismogenic Source Zones Based On Geologic Conditions, Tectonic Features And Seismicity.

V. RECURRENCE RELATIONSHIP

5.1. DeclusteringOf Catalogue

The Earthquake Catalogue Consists Of All Earthquakes Foreshocks, Main Shocks And Aftershocks. For Seismic Hazard Analysis Earthquake Catalogue Must Have The Independent Main Shocks Following Poisson's Distribution. The Foreshocks And Aftershocks Being Dependent On The Main Shocks Tend To Cluster In Space And Time Close To The Locations And Times Of Occurrence Of The Main Shocks.

5.2. Completeness Analysis

The Methods Of Completeness And Seismicity Analysis Can Be Done By Using ZMAP. The Code Is Available With Software Package ZMAP Wiemer, 2001), Which Is A Written In MathworksSoftware Matlab(Http://Www.Mathworks.Com). For The Completeness Analysis Slope Method Is Used [14].In This Analysis We Draw Time History By Using ZMAP Software For The Different Minimum Magnitudes And Estimate The Duration For Which The Earthquake Is Complete And The Slope Is Constant.

5.3. Estimation OfRecurrence Parameter 'a' And 'b'

The Recurrence Parameter 'A' And 'B' Represents The Frequency-Magnitude Relationship. Generally Occurrence Of Earthquakes Follows Gutenberg Richter Relation (G-R Relationship) [15] Expressed As:

$$\log N(M) = a - bM \tag{4}$$

Where N(M) Is The Cumulative Frequency Or Annual Occurrence Rate Of Earthquakes Of Magnitude Greater Than And Equal To M, And A And B Are Both Constants. The 'a' Value Indicates The Overall Rate Of Earthquakes In A Region, And The 'b' Value Indicates The Change In Occurrence Rate With Magnitudes. The Parameter 'b' Is Related To β;

Where, $\beta = b \times ln10$ (5)

The Parameter 'b' Can Then Be Evaluated By Using The Maximum Likelihood Method As

$$\beta = \frac{1}{\bar{M} - M_C} \tag{6}$$

$$\bar{M} = \frac{\sum M_i \times n_i}{N} \tag{7}$$

Where, N = Total Number Of Earthquake

Ni = Number Of Earthquake For Different Lower Threshold Magnitude

M_c= Magnitude For Different Period Of Completeness.

5.4. Recurrence Relation WithConstant Seismicity

In The Constant Seismicity Method, The Recurrence Rate Depends On The Upper Bound Magnitude $M_{\max}$ As Well As Lower Bound Magnitude $M_{\min}$. For The Computational Purpose $M_{\min}$ Has Been Taken As 4 In This Study And Maximum Magnitude $M_{\max}$ Can Be Determined By The Relationship Given By Kijko[16] Expressed As:

$$M_{\max} = M_{\max}(obs) + \frac{E_1(n_1) - E_1(n_2)}{\beta \times \exp(-n_2)} + M_{\min} \times \exp(-n) \tag{8}$$

Where, $M_{\max}$ = Maximum Magnitude Of Earthquake

$M_{\max}(obs)$ = Observed Maximum Earthquake Magnitude

$M_{\min}$ = Minimum Magnitude Of Completeness

N = Number Of Earthquakes Equal Or Greater Than $M_{\min}$

5.5 Recurrence Relations WithMoment Release Constraint

Before The Estimation Of Recurrence Rate By Seismic Moment Release Constraint Method We Have To Determine The Seismic Moment Associated With The Sources. According To The Kostrove, 1974 The Seismic Moment Associated With Any Volume Is Given By The Relation:

$$\dot{M}_0 = 2\mu DLW\dot{\varepsilon} \tag{9}$$

Where, L = Length In Km

D = Depth In Km

µ = Shear Modulus In Dyne/Cm^2

W = Width In Km

$\dot{\varepsilon}$ = Strain Rate In Terms Of Per Year

$\dot{M}_0$ = Seismic Moment Using Slip In Moment Ratio

This Seismic Moment Is Depend On The Strain Rate For All Sources. So The Accurate Measurement Of The Strain Rate Is Necessary.

5.6 Annual Occurrence Rate

For The Estimation Of Occurrence Rate Through Seismic Moment Release Rate, Initially We Have To Bound The Upper Limit Seismic Moment Released During The Earthquakes, Which Can Also Be Related To The Magnitude By An Expression $\dot{M}_0(M) = \mathrm{c} + \mathrm{dM}$ Where C = 16.0 And D= 1.5 For $\dot{M}_0$ In Units Of Dyne-Cm [17]. The Annual Occurrence Rate $N(M_{\min})$ Is Determined By:

$$N(M_{\min}) = \frac{\dot{M}_0(M)}{e^{-\beta(M-M_{\min})} \times \dot{M}_0(M_{\max}) \times \dfrac{b}{d-b}} \tag{10}$$

VI. Conclusion

During The Earthquake Some Of The Factors That Affect The Amplitude And Duration Of Shaking Produced By An Earthquake, I.E. Earthquake Size, Distance From Fault, Site Regional Geology, Etc., And The Shaking Caused By Seismic Waves Can Cause Damage To The Buildings Or Cause Buildings To Collapse. The Structure Depends Upon The Amplitude And The Duration Of Shaking. The Amplitude Is Highest Close To Large Earthquakes And The Duration Generally Increases With The Size Of Earthquake.

The Destructiveness Of An Earthquake Depends On Its Size, Depth And The Location. Earthquake Size Can Be Stated In Terms Of The Damage Caused (The Intensity), Or The Amount Of Ground Motion And The Energy Released By The Earthquake (Related To The Richter Magnitude). Earthquake Shakes The Ground Surface And Can Cause Buildings To Collapse, Disrupt Transport And Services, And Can Cause Fires.

To Reduce The Losses During The Earthquake, We Need To Prepare Structures For Shaking Which Can Respond To The Accelerations Transmitted From The Ground Through The Structure’s Foundation, Estimate Hazard, Strengthen Structure Either By Securing The Building Components Walls, Floors, Foundation Etc. Or Construct A Strong And Flexible Structure.

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