Structural Failure Prediction of RCC Structure Under Earthquake Using Machine Learning

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Abstract – Earthquake is a most dangerous and catastrophic disaster in the world. It is essential to introduce earthquake resistance features in construction. An earthquake -prone region must deal with the more challenging problem of earthquakes. And there is no more hundred percent earthquake proof building. The best way to avoid the building damages is to learn from the failures that can occur during a seismic event. This paper presents the failure prediction of RCC building using k-Nearest Neighbors (KNN) algorithm which can be tuned to gives up to 90% accuracy of result. A past-earthquake assessment of building data is used to train and create a model for this project to predict the necessary pattern for a future construction project. Thereby, can be predicted whether the proposed building will be collapsed or facing a minimum damage.

Key Words: Earthquake Assessment, Machine Learning, Python, K-Neighbour Algorithm, RCC Building, Failure Prediction, Site issues, Soil and Foundation Condition

1. INTRODUCTION

Earthquake, as one of the most destructive natural disasters, causes huge economic losses and casualties. Therefore, to analyse the seismic performance of structures for decision making for more effective disaster prevention and mitigation measures, researchers have carried out extensive research using shaking table tests and time-history analyses on the deformation mechanism, weak links, and characteristics of mechanical responses of structures subjected to earthquakes. The earthquake research becomes increasingly complex and consequently the building codes too. India faces threats from a variety of natural hazards such as floods, droughts, landslips, cyclones, earthquakes and tsunamis. The spate of earthquakes in the recent past, causing extensive damage has heightened the sensitivity of administrators, engineers and general public to the looming hazard due to future earthquakes occurring near densely populated Indian cities. Strong earthquakes are rare events, rarer than cyclones, windstorms and tidal waves. Nevertheless, India has seen quite a few earthquakes in the recent past. Earthquakes have occurred from pre-historic times, more or less in the same regions, where they are presently felt. The present heightened awareness towards earthquake disaster mitigation in the country is attributable to large loss of life and property suffered during the Khillari (30th September 1993), Jabalpur (22nd May 1997), Chamoli (29th March 1999) and Bhuj (26th January 2001) earthquakes.

Being situated in the seismically active zone is vulnerable to high intensity earthquakes which can lead to massive destruction of the social, economic as well as the ecological condition of the State. The rapid increase of population and urbanization has changed the building typology as the traditional houses and buildings have been replaced by non-engineered concrete structures to accommodate the population The seismic hazard or the potential of a site to experience ground motion due to an earthquake cannot be altered. The risk faced by human habitat due to earthquakes can be reduced by making man made systems and structures less vulnerable and more robust to withstand the ground motion. Seismic risk has a character to increase with time if continuous actions are not taken. This fact may be appreciated by recognizing that increasing population puts greater demands on housing, energy, water and transport needs of the society. In turn, these needs have to be met by increased construction activity of buildings, dams, reservoirs, bridges, power plants etc. Thus, even in areas of low seismic activity, the loss due to unexpected earthquakes may be high purely due to heavy infrastructure development, unless the built-up structures are engineered and maintained to withstand future earthquakes. As we take up the question of safety of manmade constructions, subtle issues crop up. It is not just new constructions that have to be made earthquake resistant. Engineers are called upon to protect existing cities, monuments and other structures built at a time when knowledge about earthquakes was limited. Moreover all types of construction may not be equally important, particularly so, when available financial resources are limited. In addition, earthquakes are low probability events with extremely high risk to the society. Damaging earthquakes are rare with their recurrence periods being of the order of several decades or centuries. But once they occur, much of the structural damage takes place within a few seconds, directly attributable to ground vibration. Hence engineers usually characterize seismic hazard in terms of the ground motion that can be experienced at the construction site. This way the dynamic response of structures can be studied to foresee where they may fail and for what level of seismic forces. This in turn helps in site selection, design and retrofitting strategies. The point to be noted here is that the quantification of hazard is needed for unpredictable future events. The nature and amplitude of ground motion at a site can be described in a probabilistic sense by combining past information with engineering methods of risk estimation.

First of all, because we want to express everything in formulas even where nature does not imagine and regardless of whether investigations are based on inaccurate assumptions. Sometimes it is difficult to understand, why if there are so much seismic research there are so many building damages all around the world. Perhaps the reason is that the practicing engineers and builders are confused with the increasing complexity of the building code. The best way to avoid the building damages is to learn from the failures that can occur during a seismic event. Structures constructed on the soil that undergoing in the deformation during ground motion that deformation or change in behavior described by the response of the structure in the form of Deformation, Velocity and Acceleration. This paper presents prediction of failure of RCC framed structures based on earthquake intensity, ground shaking effects on structures, site condition effects on building damage, other factors affecting damage, failure mechanisms of structures, earthquake damage and damage categories in past earthquake in India. Unfortunately, many buildings were built with outdated codes and regulations, thus increasing their vulnerability to earthquakes. The basic elements of reinforced concrete buildings, earthquake-resistant components such as columns, beams and shear walls, should be checked verbally and numerically with the opinion of an objective technical expert considering the physical condition of structural members, micro zonation ground velocity values, floor numbers and other related elements. Rather than the post-earthquake state, pre-earthquake assessments are critical for property and life safety. After the pre-earthquake building assessments, the buildings with "severe damage" or "collapse" results should not be allowed to enter, even for property collection. In recent years, seismic hazard assessment scale identification modelling studies of buildings have gained extensive importance as a preliminary for future planning by local and central administrative authorities' concern. In building hazard assessment studies, it is recommended that there are seismic heterogeneities affecting the stability of building engineering structures.

In general, earthquake hazard damage assessment tasks have structural and non-structural variables. The former group includes important earthquake-resistant components, while the latter concerns variables such as ground velocity, soil mechanic properties, liquefaction effects, pounding effect and like. Of course, from the mechanical strength point of view, the structural components are the most important as they provide resistance to vertical and horizontal shake loads, which are the main effects of the buildings' safety and stability properties. Any lack of one of these properties increases the buildings' hazard potential. On the other hand, non-structural components are also very important, as any miscalculation of their effects may cause a severe hazard to the building's seismic capacity design. Main focus of this project is to create logical programming to assess the structure with the past seismic response data

2. RCC FRAMED STRUCTURE

RCC frame structure is a structure in which the load is said from a slab to the beam and then the load continues to be shared to the columns. It is like a load sharing structure in which the load is getting shared from the slab to beam to columns to lower columns and to further the foundation of the structure which then shares the load with the soil. After this frame is constructed the walls are there with on this structure. Most of the tall buildings use the RCC frame structure Technology.

1. In RCC framed structure building the floor area is normally 10% to 12 % greater compared to a load bearing walled building. Hence, this type of building is preferably economical where the value of land is very high.
2. It is very easy to alternate the interior plan of a room, bathroom, W.C etc. by changing the actual position of the partition walls which ultimately gives more freedom in planning.
3. Monolithic construction can be adopted for resisting shocks and vibrations more effectively than load bearing walled buildings.
4. Normal earthquake effects can also be resisted by providing required further design.
5. Faster construction work saves time, early finishing.
6. No matter the soil is soft or hard, RCC framed buildings can be established anywhere.
7. Maintenance cost is also minimum which can be ignored.

The parts of the RCC framed structure are as follows:

1. **Slab:** The slab may be defined as the structural parts of modern buildings, containing a flat, horizontal surface prepared of cast concrete.

2. **Beam:** The beam is a horizontal structural element made up of wood, steel, or concrete that resists the lateral loads coming from the superstructure by means of bending.

3. **Plinth Beams:** In RCC framed structure, the beam on the ground level or plinth level is known as ‘plinth beams’.

4. **Column:** Columns are defined as long slender member load axially in compression and having lateral dimensions very small as compared to their lengths.

5. **Foundation:** Foundation is the substructure that transfers the load from the superstructure to the soil beneath. It is responsible for the stability of the whole structure.

6. **Cantilever:** A cantilever beam is an inflexible structural component held at one end and free at the other end. The cantilever beam can be either prepared of concrete or steel whose one end is bound or tied up to a vertical support. It is a horizontal beam structure whose free end is opened to vertical loads. For an example Balconies, lofts, and canopies.

3. FAILURES IN RCC FRAMED STRUCTURE DURING EARHTQUAKE

1. Soft And Weak Storey Mechanism

In some RCC buildings, especially at the ground floor, walls may not be continuous along to height of building for architectural, functional, and commercial reasons. While ground floor generally encloses with glass window instead of brick infill walls, partition walls are constructed above from this storey for separating rooms for the residential usage. This situation causes brittle failures at the end of the columns. In mid-rise reinforced concrete buildings, the most common failure mode is soft-storey mechanism, particularly at the first storey. Failures can be concentrated at any story called as weak storey in which the lateral strength changes suddenly between adjacent stories due to lack of or removing of partition walls or decreasing of cross section of columns. Thus, during an earthquake, partial and total collapses occur in these storeys. These types of damages can be seen in Figure 1 and Figure 2.

Figure 1. Soft and weak storey mechanism

Figure 2. Soft and weak storey mechanism

2. Short Column

This type of mechanism can be developed due to structural adjustments and/or to continuous openings at the top of infill walls between columns. Lateral forces that occurred by an earthquake are carried by columns and shear walls. Length of column is an important factor for dissipation of these loads. When the length of column decreases, the column becomes stiffer and brittle than the other columns and this column attracts more shear forces. Thus, shear failure which is a critical type of concrete column damage occurs at these columns. Short column failure is given in Figure 3.

Figure 3. Short column

3. Inadequate Gaps Between Adjacent Buildings

Buildings are sometimes constructed adjacent because of the lack of building lots. In this layout plan, one or two faces of two buildings are in contact to each other. Consequently, the buildings that have not adequate gaps pound to each other during the earthquake. If the floors of the buildings are not at the same level, pounding effect of the buildings becomes more dangerous. Figure 4 shows this type of damage during the 2003 Bingol earthquakes.

Figure 4. Inadequate Gap between the Building

4. Strong Beam–Weak Column

Deep and rigid beams are used with flexible columns in type of buildings. Therefore, these beams resist more moments, occurred by dynamic loads, than weak columns. In such a design during an earthquake while deep and rigid beams show elastic behavior, shear failure or compression crushing causes plastic hinges at flexible columns. Failure mechanism of strong beam–weak column can be seen in Figure 5.

Figure 5. Strong Beam – Weak Column

5. Failures of Gable Walls

The most common failure mode at gable walls is out-of-plane collapse in the earthquakes. Although failures of gable walls are not structural damages, these damages may be cause loss of lives and properties. Stability problems and large unsupported wall lengths cause damages at these walls. Failure of gabble wall is presented in Figure 6.

Figure 6. Failures of Gable Walls

6. Poor Concrete Quality and Corrosion

The other main reasons of damages are low concrete strength and workmanship. Concrete quality is an important factor for building performance against to earthquakes. Handmade concrete is used to without using vibrator in construction of old buildings. Thus, homogeny mixing was not obtained and expected compressive strength was not provided in these buildings. In addition to this, using of aggregates which have improper granulometry, corrosion which decreases reinforcement bar area, and using of smooth steel reinforcement effected strength of concrete. This type of damages is given in Figure 7.

Figure 7. Poor Concrete Quality and Corrosion

7. In-plane/Out-of-Plane Effect

One of the most important reasons of life and economic loss during the earthquake is combined effect of in-plane and out-of-plane movement of the wall. In-plane and out-of-plane interaction is very complicated and should be analyzed well for this phenomena. For low-rise and mid-rise unreinforced masonry (URM) infilled RCC frames, ground story infill walls are expected to be damaged firstly, because they are subjected to the highest in-plane demands. However, under the effect of bidirectional loading, where the two components of a ground motion are equally significant, infill walls of the upper stories may fail under the combination of in-plane and out-of-plane effects. The in-plane demand reduces at the upper stories, while that of out-of-plane forces increases due to the increase of accelerations. To prevent this problem, in-plane carrying capacity of the wall should **increase** and out-of-plane ductility should increase with possible and applicable developments like bed-joint reinforcements and wire mesh. These listed applications will prevent detachment of infill wall from reinforced concrete elements and will increase the stiffness of the total structural system. Figure 8 shows out-of-plane and in-plane damages.

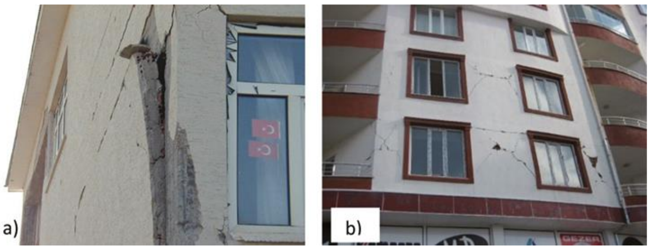

Figure 8. Poor Concrete Quality and Corrosion

8. Foundation Failure

If foundation is leaning or sinking, this could indicate foundation failure, possibly triggered by an earthquake. For homes with basements, check for walls that are leaning or bowing. If the home is built on a slab foundation, keep an eye out for any gaps or spaces between the foundation and the house itself.

Figure 9. Foundation Shifting

Interior cracks, especially those starting from door and window frames, are clear warning signs of foundation settlement following an earthquake. Drywall nail pops are also often indicative of shifting structures, which may occur when the foundation moves.

Figure 10. Interior cracks

Cracked bricks, particularly in a stair-step pattern, are a significant warning sign of foundation settlement after an

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earthquake. This type of cracking commonly occurs when one side of the foundation settles while the other remains stable, causing a disparity in weight distribution that pulls the brick walls apart. Such signs are critical indicators that the structural integrity of the foundation may be compromised.

Figure 11. Exterior Crack

Misaligned windows and doors often indicate foundation settlement after an earthquake. When one side of a frame sinks more than the other, doors and windows may stick.

Figure 12. Misaligned Doors and Windows

4. DATA PREPARATION

According to the Journal of the International Society for the Prevention and Mitigation of Natural Hazards, almost 65% of India falls in high to very high seismic zones. Zone IV is a severe intensity zone in India. It is called the High Damage Risk Zone. Jammu and Kashmir, Ladakh, Himachal Pradesh, Uttarakhand, Sikkim, parts of the Indo-Gangetic plains (North Punjab, Chandigarh, Western Uttar Pradesh, Terai, a major portion of Bihar, North Bengal, the Sundarbans) and the capital of the country Delhi fall in Zone 4. In Maharashtra, the Patan area (Koynanagar) is also in Zone4. 18% of the total area of the country belongs to Zone IV. Delhi is indeed prone to earthquakes. And Zone 5 covers the areas with the highest risk of suffering earthquakes of intensity MSK IX or more significantly. Zone-V comprises of entire northeastern India, parts of Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Rann of Kutch in Gujarat, part of North Bihar and Andaman & Nicobar Islands. It falls in seismic zone 4 along the Aravali fault line, where the probability of temblors of severe intensity is high.

So, it is decided to do my research for zone IV and V by collecting the post-earthquake assessment.

Due to lack of data in structural response under the earthquake in India, data prepared for this project by using a format mentioned in A Primer on Rapid Visual Screening (RVS) Consolidating Earthquake Safety Assessment Efforts in India National Disaster Management Authority October 2020 for RCC building. According to this paper mentioned in the Appendix1, contains the following important parameters are considered for RCC building.

Input from past earthquake impact buildings are

Building Description

Building description comprises the details of building location, zone, and number of storeys, type of structural components of a roof & slab and occupancy type of building.

The following is based on the International Building Code, the most commonly used building code

a) **Assembly (Group A) -** places used for people gathering for entertainment, worship, and eating or drinking. Examples: churches, restaurants (with 50 or more possible occupants), theaters, and stadiums. Group A is divided into five sub groups:
   i. **A-1** Buildings intended for the production and viewing of performing arts or motion pictures (theaters, concert halls).
   ii. **A-2** Buildings intended for food and/or drink consumption (restaurants).
   iii. **A-3** Buildings intended for worship, recreation or amusement and other assembly uses not otherwise classified.
   iv. **A-4** Buildings intended for viewing of indoor sporting events and activities with spectator seating (arenas).
   v. **A-5** Buildings intended for participation in or viewing outdoor activities (stadiums).

b) **Business (Group B) -** places where services are provided (not to be confused with mercantile, below). Examples: banks, insurance agencies, government buildings (including police and fire stations), and doctor's offices.

c) **Educational (Group E) -** schools and day care centers up to the 12th grade.

d) **Factory (Group F) -** places where goods are manufactured or repaired (unless considered "High-Hazard" (below)). Examples: factories and dry cleaners.

e) **High-Hazard (Group H) -** places involving production or storage of very flammable or toxic materials. Includes places handling explosives and/or highly toxic materials (such as fireworks, hydrogen peroxide, and cyanide).

f) **Institutional (Group I) -** places where people are physically unable to leave without assistance. Examples: hospitals, nursing homes, and prisons. In some jurisdictions, Group I may be used to designate Industrial.
g) **Mercantile (Group M) -** places where goods are displayed and sold. Examples: grocery stores, department stores, and gas stations.
h) **Residential (Group R) -** places providing accommodations for overnight stay (excluding Institutional). Examples: houses, apartment buildings, hotels, and motels.
i) **Storage (Group S) -** places where items are stored (unless considered High-Hazard). Examples: warehouses and parking garages.
j) **Utility and Miscellaneous (Group U) -** others. Examples: water towers, barns, towers.

Earthquake Details

To understand plate tectonic processes and hazards, and to better understand where future earthquakes are likely to occur, it is important to locate earthquakes as they occur. Earthquake details consists of **Magnitude** and **Intensity** of earthquake.

Details of Structural System

Structural system, in building construction, the particular method of assembling and constructing structural elements of a building so that they support and transmit applied loads safely to the ground without exceeding the allowable stresses in the members.

Any structure is made up of Structural elements (Beams, Columns, Slabs) and Non-structural elements (Doors, Partition Walls, Stairs).

The function of structural elements is to resist the loads acting on that structure and to transmit those to the ground.

For simplified analysis, Structural elements are classified into One-Dimensional (Beams, Columns, Trusses) and Two-Dimensional (Slabs, Plates) elements. These structural elements, put together, constitute Structural System.

Most common construction is Building (Residential, Commercial or Institutional). The Structural system and its Load transfer mechanism for a building are mentioned here in detail.

For convenience, we separate this load transfer mechanism into Gravity Load Transfer Mechanism and Lateral Load Transfer Mechanism, even though, both of these are complementary as follows.

1. **Lateral Load Transfer**
   - Rigid Frame System
   - Shear Wall System
   - Wall – Frame System
   - Braced Frame System
   - Cores
   - Tubes
2. **Gravity Load Transfer**
   - Floor Systems
   - Wall – Slab System
   - Beam – Slab System
   - Ribbed Slab System
   - Flat Slab System
3. **Vertical** System
   - Columns
   - Walls

Siting Issues

There are various site conditions evolved in damage condition of RCC building under seismic waves. Some of the life threatening issues are as follows, which are considered in this paper.

1. Building is resting on ground that has failed due to Landslide/Fissures and Liquefaction.
2. Building is resting on hill slopes or adjacent to hill slopes, and has unsafe/tilted adjoining/uphill building or loose boulders.
3. Building is adjacent to a failed slope.
4. Building is adjacent to a failed slope
5. Building is built on hill slope or adjacent to hill slope, that is vulnerable to falling debris.
6. Building rests adjoining a severely deteriorated or damaged building or structure
7. Building is resting on cracked ground
8. Building is adjoining another building on the side with no gap.
9. Building is resting on river terraces that have cracked soil

Soil and Foundation Conditions

Soil conditions have a great deal to do with damage to structures during earthquakes. Hence the investigation on the energy transfer mechanism from soils to buildings during earthquakes is critical for the seismic design of multi-story buildings and for upgrading existing structures.

Seismic waves have a significant impact on the soil foundation of a building, leading to various effects and consequences. The interaction between the soil and the structure during an earthquake can result in increased shear stresses in the bottom storeys of the building, causing it to become less rigid and leading to lateral displacements such as storey drift, inter-storey drift, and roof displacements [1]. The stability of the building can be affected by the weakening of the soil, which can result in the overturning of the structure. The followings are the life threatening site conditions of soil and foundation, which are considered in this paper.

1. Building is built on liquefiable soil.
2. Building is built on river terraces that can slide or creep.
3. Building is built on hill slope that can slide.
4. Building is resting on weak or non-uniform soil along the length in plan.

Architectural Features

Architectural planners must give due consideration to seismic events as they present substantial hazards to both critical infrastructure and human well-being. It emphasizes the importance of seismic hazard assessment, design standards, structural systems, and cutting-edge technology in reducing earthquake-related dangers. Sometimes the shape of building catches the eye of visitor, sometimes the structural system appeals, and in other occasions both shape and structural system work together to make the structure a Marvel. If the building is irregularly shaped there will be excessive deflection and twisting moment during earthquake. The architectural problem includes the different aesthetically good looking structure with irregularities. The irregularity may be plan or vertical irregularity, this includes soft storey, L-shape, T-shape building, large horizontal size of building and square building with a central opening.

Construction and Maintenance Details

The correct building materials need to be used in such earthquake prone zone. Materials that can withstand bends and movement should be selected. To make your construction resistant from lateral forces of the earthquake is to tie the walls, floor, roof, and foundations into a sturdy box that holds them together. To guarantee continuous functionality of structures after seismic events, suitable maintenance strategies before and after earthquakes should be considered.

5. MACHINE LEARNING ALGORITHMS AND RESULT

Machine learning contains a set of algorithms that work on a huge amount of data. Data is fed to these algorithms to train them, and on the basis of training, they build the model & perform a specific task.

These ML algorithms help to solve different business problems like Regression, Classification, Forecasting, Clustering, and Associations, etc.

But here we are using on the K-Nearest Neighbor algorithm for predicting the structural failure of RCC Structure under earthquake.

Figure 13 shows the Accuracy of the KNN algorithm

```
[[41  0 20 48  0 17  3]
 [ 0  0  1  0  0  0  0]
 [25  0 24 57  0 18  3]
 [51  0 46 54  0 31  5]
 [ 2  0  4  4  0  2  0]
 [34  0 34 60  0 23  0]
 [ 8  0  6 17  0  8  1]]
                                  precision    recall  f1-score   support

                         Collapse       0.25      0.32      0.28       129
                Damage Assessment       0.00      0.00      0.00         1
       Moderate structural damage       0.18      0.19      0.18       127
         Severe structural damage       0.23      0.29      0.25       187
         Slight structural damage       0.00      0.00      0.00        12
Slightly non -structural damage       0.23      0.15      0.18       151
              no damage but tilted       0.08      0.03      0.04        40

                         accuracy                           0.22       647
                        macro avg       0.14      0.14      0.13       647
                     weighted avg       0.21      0.22      0.21       647
```

Figure 13. Confusion Matrix and Classification Report

6. CONCLUSION

Construction defects and weaknesses are rapidly identified among 3000 sample buildings are examined through Machine Learning. KNN Algorithm used to train the model with the provided dataset, fine-tuned to give up to 90% accuracy of result and produce model. Finally web application that developed using flask framework that provides the interface for the user to fill in the structural aspects to predict the failure. This web application will evaluate the model and return the outcome on the screen. Using the python flask framework for user to input the structural properties and the failure of RCC building has been predicted. Pre-earthquake building assessment is a promising approach to assess the seismic vulnerability of buildings. Further research is necessary to develop logic modelling approaches because whatever the input parameters are, there will always be uncertainties in numerical and especially verbal information forms.

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