

# EARTHQUAKE RESISTANT STRUCTURE USING SEISMIC CLOAKED FOUNDATION

ANUP SHELAR<sup>1</sup> and MIRAJ THAKER<sup>2</sup>

Civil Engineering, Universal College of Engineering, Mumbai, India

\*\*\*

**Abstract** - Structures are subjected to an earthquake excitation, it interacts with the foundation and soil, and thus changes the motion of the ground. It means that the movement of the whole ground structure system is influenced by the type of structure as well as type of soil such as dense soil, medium and soft soil. Different soil properties can affect seismic waves as they pass through a soil layer. The study of seismic resisting foundation with its analysis, the behavior of surrounding soil and the designed foundation, feasibility and its implementation. The behavior of seismic waves throughout the soil layer and designed foundation will be comparatively studied and analyzed by simulation modeling. The designed foundation will be in the form of concentric rings and each concentric ring consisting of different types of materials such as rubber sheet with reinforcement mesh which has the ability of elastoplasticity which reduces the seismic effect. The foundation structure will represent like rings filled with materials in concentric manner and model analysis will be performed and the results will define the feasibility of the test.

**Key Words:** seismic waves, concentric rings, rubber sheet, elastoplasticity

## 1. INTRODUCTION

This document is template. We ask that authors follow some simple guidelines. In essence, we ask you to make your paper look exactly like this document. The easiest way to do this is simply to download the template, and replace(copy-paste) the content with your own material. Number the reference items consecutively in square brackets (e.g. [1]). However the authors name can be used along with the reference number in the running text. The order of reference in the running text should match with the list of references at the end of the paper.

The problem of earthquake cannot be over emphasized. More than about 60% of the land area is considered prone to shaking of intensity VII and above (MMI scale). In fact, the entire Himalayan belt is considered prone to great earthquakes of magnitude exceeding 8.0, and in a short span of about 50 years, four such earthquakes have occurred: 1897 Assam (M8.7), 1905 Kangra (M8.6), 1934 Bihar-Nepal (M8.4), and 1950 Assam-Tibet (M8.7).

Foundation is a substructure built below the super structure. Purpose of the foundation is to transfer the structural loads safely to the underlying soil. Safe and

economical design of a foundation under different loading conditions is the role of geotechnical engineer. Earthquake loads are the most complicated and complex. Design of earthquake resistant foundation is highly challenging. Proper design of a foundation against earthquake loading requires through understanding over the behavior of soil, response of structure and interaction of soil-structure under earthquake loading. If a building's foundation sits on soft or filled-in soil, the whole building may fail in an earthquake regardless of the advanced engineering techniques employed. Assuming, however, that the soil beneath a structure is firm and solid, engineers can greatly improve how the building-foundation system will respond to seismic waves. For example, earthquakes often knock buildings from their foundations. One solution involves tying the foundation to the building so the whole structure moves as a unit.

## A. HISTORICAL STUDY

The first major initiatives for earthquake resistant constructions emerged after the Baluchistan (now in Pakistan) earthquakes of the 1930's. After the Mach earthquake of 1931 (M7.4; intensity VIII on RF scale), about 60 km from Quetta, formal earthquake resistant construction was carried out in the region for the railways. S.L. Kumar, the young railway engineer who designed these constructions, documented this work (Kumar 1933), provided the first seismic zone map of the country and suggested seismic design coefficients. In the 1935 Quetta earthquake (M7.6; intensity upto X on RF scale; about 20,000 dead), the earthquake-resistant railway quarters located in the area of maximum damage were the only houses that remained undamaged.

Clearly, the 1935, Quetta earthquake was interesting from several viewpoints. For the first time, serious and systematic efforts were made in the country at earthquake resistant constructions and for developing earthquake codes. More importantly, for the first time in India, efficacy of earthquake resistant constructions was tested during a severe earthquake.

The evolution of the provision of reinforced concrete bands at plinth, lintel, and roof levels in masonry buildings took place after this earthquake. In fact, the actions taken subsequent to the 1935 Quetta earthquake provided the model to be recommended for other earthquake-prone regions of the country.

The concrete industry developed an early interest in earthquake engineering. The Indian Concrete Journal brought out a special issue (ICJ, 1934) on the 1934 Bihar-Nepal earthquake with excellent well-captioned photographs. After the Anjar (Cutch) earthquake of 1956, two articles (ICJ, 1956a; ICJ, 1956b) were published in the same journal outlining the design principles of earthquake-resistant buildings. A monograph on earthquake resistant buildings was published in 1954 which was revised in 1958 and 1965 (CAI, 1965). School of Research and Training in Earthquake Engineering (now Department of Earthquake Engineering, DEQ) was set up at Roorkee in 1960.

The important research projects undertaken at Roorkee in the early years include: lateral resistance of masonry walls and enclosures, development of indigenous strong motion instruments, and studies on liquefaction. Research on base isolation of masonry buildings was conducted at DEQ as early as 1970's. Several innovative experimental set ups were developed at Roorkee to conduct research, including a two-dimensional shake table. DEQ provided earthquake engineering consultancy for major dams and nuclear power plants; for instance, the Narora atomic power plant located on a site with deep alluvium (zone IV) and the rock-fill dam at Tehri in the Himalaya (zone V).

## B. IMPORTANCE

Earthquakes have many aspects to study - its size, location, waveform, damage pattern, causative factor, distribution pattern and after-effects. Every aspect has its own importance. It depends what is your area of specialisation and where you want to enter into this subject.

By studying the size and location, we can decipher the origin and frequency of occurrence in terms of its size and spatio-temporal distribution. This will enable us to classify the area into seismic zone in terms of earthquake proneness. This is the area of interest for geophysicists. By analysing the damage pattern, we can design the buildings in the area which can resist such damages in the wake of any impending earthquakes. This can be numerically simulated also. This is the area of civil engineers. To analyze the depth of earthquake and ascribe it to any known fault plane or draw a new one if not already mapped. The stress build-up pattern.

## C. OBJECTIVE

To prevent building collapse during earthquakes thus minimising the risk of death or injury to people in or around those buildings. Because damaging earthquakes are rare, economics dictate that damage to buildings is expected and acceptable provided collapse is avoided.

To provide the structure with resistance to the forces by controlling the impact at the base of foundation and to

suppress the development of undesirable response modes which could lead to building collapse, to reduce cyclic rotational movements and soil liquefaction.

To make the foundation to act as elastoplastic membrane absorbing the lateral impacts thereby reducing its effects on the structure by providing a safety factor.

## 2. METHODOLOGY

Various methods have been introduced in the structures to make it resistant to earthquake to make it safe but what if suitable methods for making the foundation resistant to earthquake would be adopted. A structure feels the seismic impact when the lateral forces that is the surface waves (Rayleigh waves and love waves) come in contact with the footing of the foundation. It makes the whole structure to wave further leading to collapse. This impact of waves can be reduced at the contact by cloaking the footing of the foundation by energy absorbent materials which are flexible and ductile to the horizontal forces acting on it. These materials will help in reducing the shocks which are to make contact with the structural base.

Assumptions are to be made for practical purposes which makes the concept applicable to those conditions only like Soil beneath the structure is uniform and stiff, Only lateral forces act at the foundation, The footing rests on the hard strata.

To observe and analyze the results and behavior of structure, a whole unit consisting of structure and foundation techniques is setup and the following setup is then subjected to cyclic hammering impact creating shock waves throughout the soil structure.

## 3. CONSTRUCTION

The setup consists of a structure of ratio b:h of 1:4 i.e. breadth of structure is 20cm and height is 80cm. The structure being divided into 8 floors of 10cm and the structure is made up of acrylic sheets and angles glued together. Top floor and bottom floor being fixed with gyroscopic sensors to measure the interstorey drifts of the structure in all three directions and the torsional moment. The sensors are fixed on the top and the bottom beam of the structure. The footing of the structure is a stepped footing consisting of 5 steps made of acrylic sheet with all the dimensions shown in the Figure 3.1 and Figure 3.2

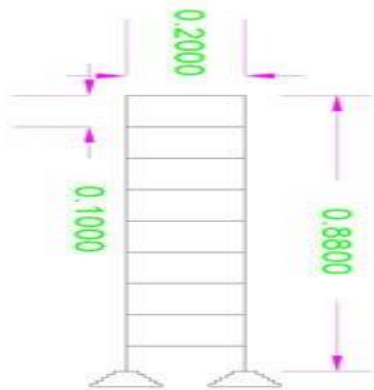


Figure 3.1: Building Elevation

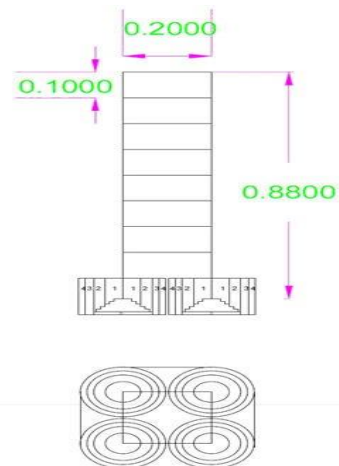


Figure 3.3: Assembly with cloaked technique

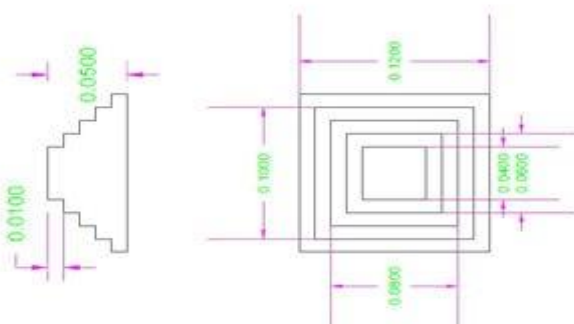


Figure 3.2: Footing Details

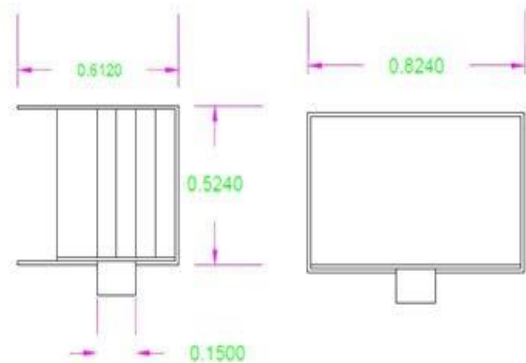


Figure 3.4: Wooden Confinement with layered soil filled

These footings are cloaked by concentric neoprene rubber sheets[3](6mm thick) which forms part of the outer concentric rings followed by a ring of polyethylene terephthalate foam core[2](8mm thick) with stainless steel spirals in it. This ring of steel spirals is filled in the lower part of the concentric ring while the upper part is filled with foamed plastic polymers[1]. The whole cloaked assembly is surrounded with steel mesh providing protection against the adjacent rock/soil mass[4]. The dimensions and the material details are given in figure 3.3. Circular geometry is recommended due to its suitability for grouping. Circular cylinders collapse in a row-by-row manner without transmitting large forces to the supporting structure and are less affected by impact angle than square cylinders. The materials used are based on decision due to relatively low stiffening ratio (3.550), relatively high energy dissipation, and environmental resistance.

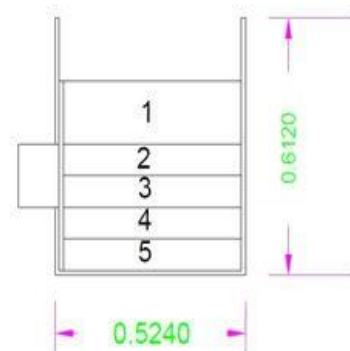
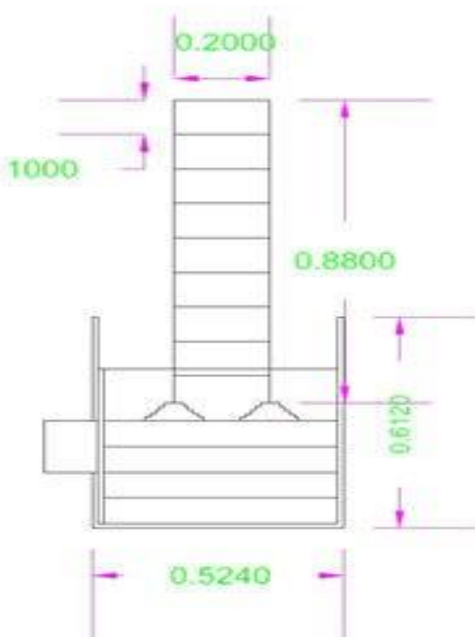


Figure 3.5: Soil Layers

Further this whole assembly rests on confined soil which are layered and artificially compacted by ramming each layer with a 10lbs rammer. The different types of soils used in each layer are detailed in the diagram given below. The confinement is made of wooden ply of 18mm thick with dimensions of 0.8m×0.5m×0.6m with a circular hole (diameter- 13cm) at one of its width. This hole is provided to fit the hammering system in it. The hammering setup consists of a ply of 0.8m×0.5m fixed with a timber cylinder of height 10cm and diameter 12cm at the centre of the hammering ply. This part is further fitted in the hole cut in the wooden confinement and then the soil is filled in layer.



The types of soil used to represent the upper crust are

- a. Earth filling
- b. Rocks
- c. Aggregate and Sand
- d. Silt
- e. Clay

The whole confined soil is assumed to act as the top crust layer of the earth, which is excavated and The concentric 2 outermost ring consisting of structure is installed in that area with that cloaking technique around the footing.

## 5. PROCEDURE

The whole wooden confinement was made with plywood and to create the vibrations/shock waves in the soil the hammering plank apparatus was designed for creating a satisfactory impact on it. First the confinement was filled with clayey soil excavated from the nearby site and was compacted by a rammer of 10lbs till the height of soil was about 12.5 cm.

The third layer from bottom consist of aggregate of 40mm filled with fine sand to fill the voids and was then compacted to a depth 12.5cm. The fourth layer was filled large boulders and loamy soil upto a depth of 12.5cm over which a layer of earth was spread for making a flat base.

Then at the centre the structure was kept such that the building is leveled in all directions with the help of a level tube on the layered soil.

The structure was then filled by earth at the remaining area so as to make it embedded in the soil upto at height of 20 cm and was thoroughly rammed to make the soil layers to act as well compacted and undisturbed strata.

After all the setup was ready, for testing the behavior of the building under vibrations, accelerometer and gyro sensors were fitted at the top and the bottom beam which would give the displacement and angular twist of the structure due to shock waves in all x, y and z direction.

A piezometric sensor was fitted at the cylindrical timber face were the blows by hammer was to be given to detect vibration or a knock produced while the hammer is hitted. The testing is then commenced by giving medium blows on the cylindrical timber face and these connected sensors gives the digital data on the computer screen. After that a graph is prepared digitally on excel by inputting the result data giving wide perspective on the behavior of structure subjected to shock.

The next part of the experiment was to test the structure with the cloaked technique installed with it. The soil around the footing was excavated about 20cm of depth in a rectangular shape manner and the structure was kept in the excavated pit and below each footing rubber sheets of 0.8m×0.8m was laid.

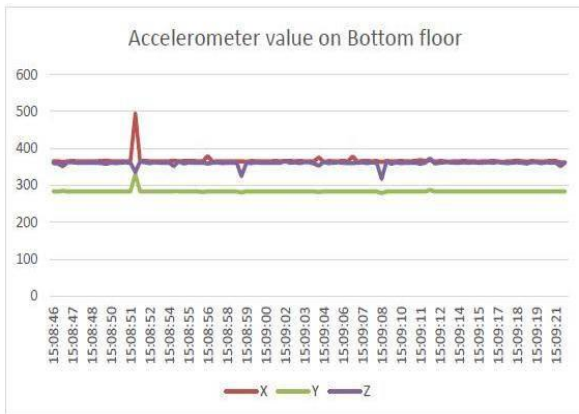
Around each footing rubber sheets of diameter 18cm is rolled to form a hollow cylinder of 12cm height which forms the outer concentric ring. Nd.

The next layer of soil was silt which was well compacted upto a depth of 12.5 cm. polyethylene terephthalate foam core is rolled into 16cm in diameter of about 2cm thick.

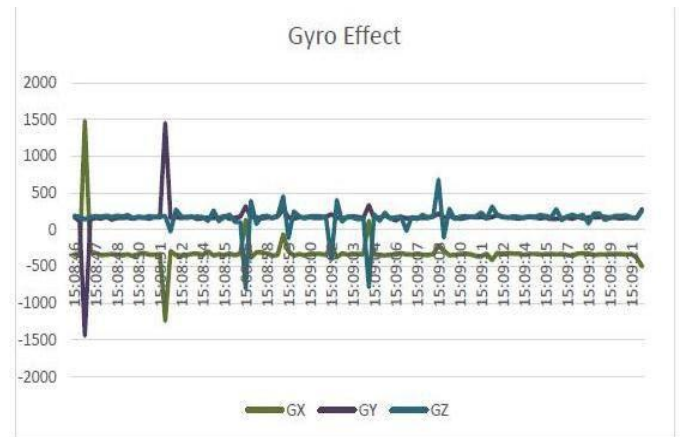
The inner ring or the core ring is filled with stainless steel spirals and foamed plastic polymers throughout the height. These concentric rings are protected by steel mesh surrounded around the cloaking technique throughout all the four cloaked footings.

After that the remaining excavated area is backfilled with soil and is compacted well. The testing is then performed in the similar way as in the conventional isolated foundation and results were then obtained digitally.

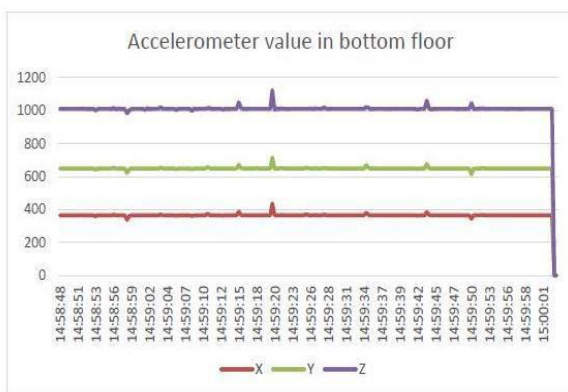
**RESULT**



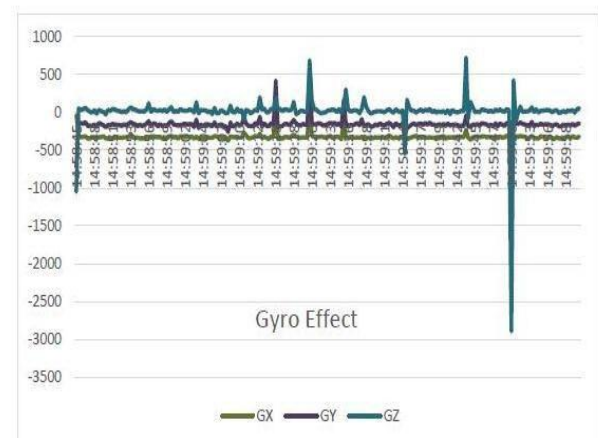
Graph 4.1: Acceleration vs Time graph in X, Y and Z direction of bottom floor (Conventional footing)



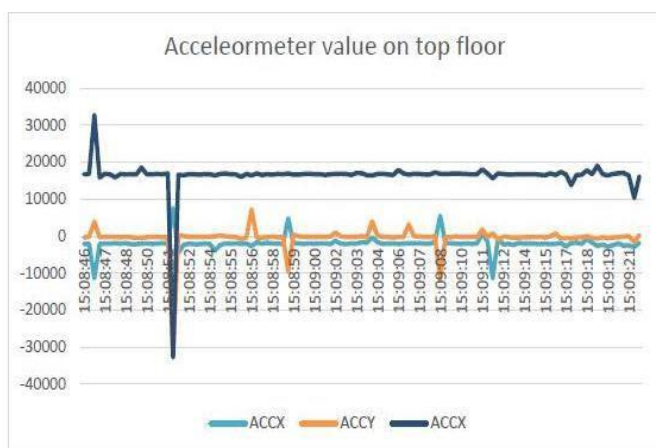
Graph 4.3: Gyro vs Time in X, Y, Z direction (Conventional footing)



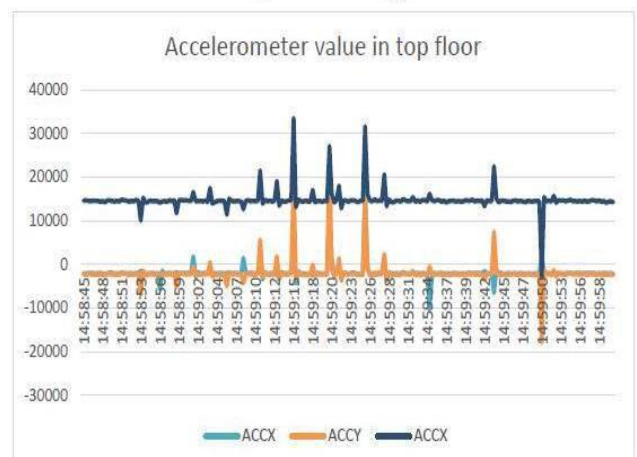
Graph 4.5: Acceleration vs Time graph in X, Y and Z direction of bottom floor (Cloaked Footing)



Graph 4.7: Gyro vs Time in X, Y, Z direction (Cloaked footing)



Graph 4.2: Acceleration vs Time graph in X, Y and Z direction of top floor (Conventional footing)



Graph 4.6: Acceleration vs Time graph in X, Y and Z direction of top floor (Cloaked Footing)

By comparing the result in the form of graph from both the tests it was out that cloaked footing gave good results as compared by that of conventional footing technique used. The acceleration in x, y and z directions were comparatively less from the previous taking in the point of the impact force applied. In the second test, the impact force was about 150N as compared to previous test which was 40N. The gyro effect (moment along the axis of building) of cloaked footing was as comparatively less from conventional technique. (All these results were obtained from the graph comparatively). By taking into consideration all the factors governing the stability of the structure and the economy, the feasibility of certain project will be decided. As far as the results are concerned, the feasibility of the technique can be seen in a positive way. The materials which are used having elastoplastic properties try to negate the incoming vibrations but the implementation of these materials on a large scale would not be a good idea since these materials wouldn't cause a much difference in mitigating the seismic forces. On a large scale the magnitude of the seismic waves will adversely affect these material properties, so materials to be used on a large should have a property of de-intensifying the waves to half of their magnitude. With the upcoming researches efforts are being made to introduce Metamaterials which have electromagnetic properties which decreases the effects of waves to greater extent. Similar technique as one adopted in these project can be adopted and introduction of metamaterials in place of elastoplastic materials should be tested.

## CONCLUSION

The Cloaked foundation technique was developed to test its ability to act in case of a quake is struck to a structure and finding the results of the test which turned out to be a good one. The technique adopted resisted the effects of vibrations to certain extent thereby minimizing the hampering of the stability of the structure. It was seen that the displacement and acceleration was reduced comparatively when the footing was cloaked with elastoplastic materials. These materials try to negate the incoming vibrations coming on the structure but the implementation of these materials on a large scale would not be a good idea since these materials wouldn't cause a much difference in mitigating the seismic forces. Others techniques have also been discussed in the paper which can be explored more and researched, which might turn out to even more feasible than the adopted technique.

Considering implementation of this technique on a large scale the magnitude of the seismic waves will adversely affect these material properties, so materials to be used on a large should have a property of de-intensifying the waves to half of their magnitude. With the upcoming researches efforts should be made to introduce Metamaterials which have electromagnetic properties which decreases the effects of waves to greater extent. Similar technique as one adopted in these project can be adopted and introduction of metamaterials in place of elastoplastic materials should be tested and also certain ways must be found out to tackle this problem naturally like the one discussed about the Forest Coverage acting as a metawedge. Seeing the present scenario and future dangers methods must be found out to not only tackle the problems of earthquake but other natural calamities too.

## REFERENCES

- [1]Parton and Meville Smith, "Effects of Soil properties on Earthquake.
- [2]M. Vucetic, "Soil properties and Seismic response", University of California at Los Angeles, USA, 1992.
- [3]Samsher Prakash and Vijay Puri, "Foundations under Seismic loads"Department of Civil Engineering, Missouri University of Science and Technology, Rolla.
- [4]Phil Mckenna, "Cloaking Buildings from Earthquakes and Tsunamis",
- [4]Berhous Gordan, "Effect of Material Property in Foundation during Earthquake", Faculty of Civil Engineering, University Teknologi Malaysia.
- [7]Qiujiao Du and Yi Zeng, "Elastic metamaterial-based seismic shield for both Lamb and surface waves", 2017.
- [5] Foundations", School Of Civil Engineering, KIIT University, Bhubaneswar, Odish