A Thesis on

To study the effect of seismic loads on concrete silo structures

Submitted for partial fulfillment of the requirement for the award of degree

MASTER OF TECHNOLOGY

IN

Structural Engineering

By

Abdullah Aiman

(Roll No-2001431001)

(Enrollment No- 2000101780)

Under the Supervision of

Md Tasleem

(Assistant Professor)

DEPARTMENT OF CIVIL ENGINEERING

INTEGRAL UNIVERSITY,

LUCKNOW-226026(U.P.)

2022

DECLARATION

I Abdullah Aiman declare that thesis **“To study the effect of seismic loads on concrete silo structures”** submitted by me in the partial fulfillment of the requirements for the award of the degree of Master of Technology (Structural Engineering) from Integral University, Lucknow. The thesis is record of my own work carried under the supervision and guidance of **Md Tasleem (Assistant Professor).** The Thesis has been composed by me and that the work has not been submitted for any other degree or professional qualification. I also declare that in case of any discrepancy I will be solely responsible. I confirm that appropriate credit has been given within this thesis where reference has been made to the work of others.

Place: Lucknow

Name: Abdullah Aiman

Roll No: (2001431001)

Department Of Civil Engineering

Integral University, Lucknow

CERTIFICATE

Certified that the thesis entitled **"To study the effect of seismic loads on concrete silo structures"** is being submitted by **Abdullah Aiman** (Enrollment No-2000101780) in partial fulfillment of requirement for the award of degree of master of technology (Structural engineering) from integral university, Lucknow, is a record of candidate's own work carried out by him under my supervision and guidance The results presented in this thesis have not been submitted to any other university or institute for the award of any other degree or diploma.

Md Tasleem

(Assistant Professor)

Department of Civil Engineering

Integral university, Lucknow – 226026

ACKNOWLEDGEMENT

I would like to acknowledge and give my warmest thanks to my respected supervisor **Md. Tasleem (Assistant Professor**) who made this work possible. His guidance and advice carried me through all the stages of my thesis work. I would like to express my heartfelt gratitude for my research guide **Md. Tasleem (Assistant Professor)** who provided me useful inputs at each and every stage of this research work. He taught me with practical approach to solve a problem and get the accurate result in simplified manner. I feel blessed to have worked so closely with him and gained a lot through his knowledge and experience.

I would also like to give special thanks to **Prof. Dr. Syed Aqeel Ahmad**, (**Head, Department of civil engineering),** INTEGRAL UNIVERSITY, LUCKNOW for providing me vital suggestions and necessary arrangements in the department. All staff members of Department of Civil Engineering are gratefully acknowledged for their cooperation and support.

Last but not the least I would like to thank my family members who supported me through this entire work. They encouraged, motivated and helped me thorough every ups and downs during my thesis work.

Date:

ABDULLAH AIMAN

(Enrollment No- 2000101780)

TABLE OF CONTENTS

Contents	Page No

List of figure

List of tables

List of symbols

P	Pressure
γ	Unit weight
µ	Coefficient of friction between bulk solid and silo wall
K	Ratio between horizontal and vertical pressure
θ	Angle of internal friction
y	Depth measured from top of silo
R	Ratio of cross-sectional area of fill material to perimeter ofsilo
A	Cross-sectional area of silo
U	Interior parameter of the silo
D	Diameter of silo

ABSTRACT

Silos are non-building structure that is used for storage of variety of granular and powdery materials. Every Year large no of silos are either damaged or collapsed due to natural calamity and earthquake is most important among them. To ensure the safety and effective functioning of silos, the researchers need to understand the complex behavior of stresses generated on silo walls and hopper. Its geometry, seismic factors, soil condition, nature of stored material play vital role in its working and construction. This thesis throws some light on the seismic analysis of concrete silos with conventional concrete and concrete mixed with glass fibers in terms of base shear and displacement. As researches proves that introduction of fibers in concrete improves its strength, durability, impact resistance, crack resistance and toughness. The same property has been used, which resulted in better results in terms of displacement, member forces and flexural capacity. The Modeling, design and analysis is performed on SAP2000 software. The silo is elevated on columns that are fixed in the ground. One model is composed of M40 grade concrete and other model is also M40 concrete mixed with glass fiber as admixture. The effect of lateral loads especially due to wind and earthquake is critical in determining the stability of stack like structure such as silo. Therefore, the effect of base shear and displacement is compared with increasing height. It was found out that concrete mixed with glass fibers has shown lesser displacement along height and lesser lateral force was generated in it as compared to the conventional concrete. Also, the capacity to resist bending moment and shear force was found more in M40 concrete mixed with glass fiber. The overall results of M40 concrete mixed with glass fiber were found better and more satisfactory than conventional concrete.

CHAPTER 1
INTRODUCTION

1.1 General

Silos are the structures meant for storing materials like food grains, cement, coal, ore, crushed stone etc. in large quantity. Silos generally work as a storage structures between supply and demand of various goods and agricultural products and their safety is matter of interest for structural engineers. In last few decades, many of these structures were damaged natural calamities, among which the earthquake was the most significant. Adequate seismic design of silos is especially important in the field of plant engineering since structural damage often leads to consequential damage such as fires, explosions, and the release of toxic substances into the air and soil.

The thesis work deals with seismic analysis of storage structures such as concrete silos. The various forces involved during earthquake and its effect on the components of silos. The stability parameters of its elements are analyzed against lateral loads. Seismically excited silo structures have long been the subject of intensive research. Researchers have been trying to understand the impact of seismic waves on tall and slender structures like silos and what potential damage it can cause to a silo.

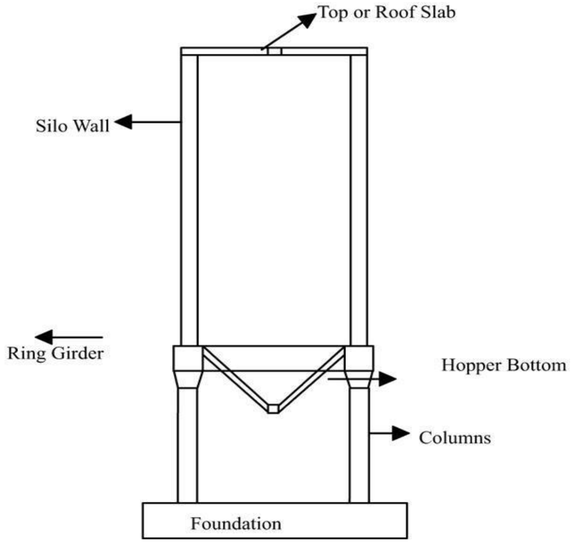


Figure 1.1- Components of a silo [8]

Before 1900 the majority of silos and bins constructed to store bulk granular materials were fabricated from steel plate or wood. As most of these silos and bins were relatively small, they performed quite well, even though the engineers of that period were, to some degree, ignorant of the magnitude and distribution of forces created by the stored material at rest and in motion. Increases in agricultural production of small grains during this period (1870-1900) created a demand for silo units and groups of larger height and cross-sectional area. Many of these were designed by extrapolating the design used for smaller silo groups. By the early 1880s enough structural failures had occurred to warrant experiments by a number of engineers to determine the distribution and intensity of the forces created by the stored material. It gradually became apparent that there were economic limitations on the use of steel plate and wood to construct these larger silo units. Thus the use of other materials and construction methods became feasible. The first recorded construction of a reinforced concrete grain silo in the United States occurred in 1899 when the Peavy Company had a single grain silo constructed in St. Louis Park, Minnesota. Slip form concrete construction is the uninterrupted vertical molding or extrusion of reinforced concrete walls by the use of a forming system that is raised by mechanical means in small (to 1 in.) but continuous increments, while concrete and reinforcing are placed in the open top of the forms.

1.2 Types of silos

Storage structures like bins (silos and bunkers) for storing different materials are one among the important structures coming up in any industrial or organized storage complex. The necessity to store and contain materials like coke, coal, ores in the various steel plants and other industrial establishments cannot be overemphasized. In cement factories as well as in construction projects, cement is stored in large silos. On the agricultural front the food grain storage structures playa vital role in ensuring the supply of food grains at all times of the year.

Materials	Particle size
Granular	> 0.2 mm
Powdery	< 0.06 mm

Table 1.1 – Classification of materials [17]

On the basis of types of material used in the construction, basically there are two types of silo

1- Reinforced cement concrete silo

2- Steel silo.

In this thesis work, a reinforced concrete silo supported on the column elevated from ground and having a conical hopper is discussed and analyzed.

1.2.1 Foundation of silo

Many types of foundation are used for silos, including: concrete mats (or rafts), multiple spread footings, ring-type footings, combined footings, friction piles, bearing piles, and caissons. In some cases, bedrock itself may serve as the foundation, the silo walls resting directly on rock. The individual in charge of silo design should study thoroughly the soils report and any other material available on soil conditions at the selected site. Based on this information, he should determine the type of foundation most suitable for the specific project.There may, of course, be more than one suitable type; in this case a comparative study should be made of cost, practicability, and safety, to select the most suitable.

Continuous raft foundations are the most frequently used type for either single or grouped silos. A continuous raft minimizes the harmful effects of unequal settlements and helps overcome the problem of low soil bearing values. Raft foundations are feasible even when substructures are present that require significant indentation of the raft top surface, such as thru or rail car scales or discharge. A raft of uniform thickness is usually most economical. However, a ribbed raft, may be advantageous under a system of columns. A two- way system of ribs placed along column rows serves as beams to distribute the column loads to large areas of raft. The raft can then be thinner than it might be without ribs.

To avoid tilting, the centroid of the raft should preferably coincide with the location of the resultant maximum vertical load. If this is not practical, the eccentricity should be kept as low as possible. A raft foundation "bridges" over relatively soft spots in the soil, bearing more heavily on the harder spots. Although this is an advantage and a reason for its use. It also makes accurate computation of raft shears and bending moments virtually impossible. The same condition exists, of course, on smaller units even on a stall spread footing. The problem caused there is trivial, but on the large raft foundation it is a major factor.

1.2.2 Importance of silo

Storing of bulk materials in silos is essential to agricultural, mining, mineral processing, chemical, shipping, and other industries. Silos and bunkers may serve for either long-term or short-term storage; commonly, though, silos serve as long-term storage facilities. Both are used for storing finished materials as well as for intermediate storage of unfinished and raw products. Silos may either singly or in groups may serve as terminals for receiving and shipping. Such terminals usually involve multiple transportation modes; for example, material arriving by truck may be stored in the terminal temporarily and then discharged into train, barge, or ocean-going vessel for shipping elsewhere. Terminals usually have sophisticated systems for weighing materials being received and shipped.

1.3 Design Criteria

1.3.1 Dimensions- Volume of each bin and height to diameter ratio shall be governed by its storage and functional requirements of materials. To achieve a reduction in lateral pressure over a larger height, it may be preferable to select a height/diameter ratio greater than or equal to two.

1.3.2 Shape- A bin maybe circular or polygonal in plan and is provided with a roof and bottom which may be flat, conical and pyramidal. In case of gravity flow bin, the angle made by the hopper with the horizontal, shall preferably be 15° more than the angle of repose of thestored. The cross-sectional shape of the bin is taken into account by the factor **R = A/U** whereA is the interior cross-sectional area of the bin and U is the interior perimeter of the bin. In the case of interstice bins, the value of R shall be approximated by the value of R for an equivalent square bin of the same area.

1.3.3 Layout- Storage bins may be either free standing individual bins or arranged in the form of batteries of free-standing bins or bins inter-Connected in one or both the directions.

1.3.4 Bulk density and angle of internal friction- Table 1 of I.S. 4995 (part 1) gives the value of bulk density and angle of internal friction of some commonly stored materials like food grains, ash, coal, coke, ore etc.

1.4 Design loads

The following loading conditions and effects shall be considered while designing the various components of a storage bin namely, roof, bin walls, ring girder, hopper bottom, supporting columns and foundation:

a) Dead load of the silo

b) Weight of the stored material

c) Seismic loads on the silo

d) Superimposed loads due to material handling and transportation machinery if any:

e) Effects due to temperature variation.

1.4.1 Assessment of loads due to stored material

There are three types of loads caused by a stored material on the circular walls of the silo. They are described below-

a) Horizontal load or horizontal pressure acting on the side walls,

b) Vertical load or vertical pressure acting on the cross-sectional area of the silo wall

(c) Frictional wall load or frictional wall pressure introduced into the side walls through wall friction.

Here, Janssen's theory has been used to calculate silo loads, in this bulk density and pressure ratio is assumed to be constant throughout the bin height. The walls of silo are designed to resist bending moment and tension caused by pressure of contained material. The horizontal pressure at depth h below the free surface being related to material parameter k by the equation as shown in the equation

$$P = \frac{(1 - e\hat{}(-2K\mu \frac{y}{r}))}{2\mu}$$

In which K = ratio of horizontal to vertical pressure, which is assumed equal to Rankine's coefficient of active earth pressure.

$$K = \frac{1 - \sin\theta}{1 + \sin\theta}$$

It has been observed analytically that,

$$\frac{1-\sin\theta}{1+\sin\theta} < K < 1$$

Some important geometric parameters taken into considerations are as follows,

$$R = \frac{A}{U}$$

$$A = \frac{\pi D^2}{4}$$

$$U = \pi \times D$$

Where,

A = interior cross-sectional area of the silo

U = interior perimeter of the silo

R = A/U.

D = internal diameter of silo wall

θ = Angle of internal friction of stored material

µ = Coefficient of friction between stored solid and silo wall.

1.5 Discharge promoting devices

Modern silo storing various materials may be provided with various discharge promoting devices such as inserts, bridge like structure above the outlet or relief nose. In all such cases the effective cross section of the silo is locally reduced. Recent research has given an indication that in such silo the horizontal wall pressures arc excessively increased locally or along the entire wall height. In the absence of reliable knowledge available on the subject the designer is cautioned to assess the wall loads for such silo most judiciously and by carrying out experimental investigation.

Openings required for manual access to the bin or for spout inlets, aeration, temperature detection, etc. shall be left during the process of concreting. Breaking the previously laid concrete for this purpose shall strictly be avoided. These openings shall be provided with airtight covers. Openings shall preferably be avoided in the zones of critical stresses. Small openings of size less than or equal to five times the wall thickness shall be treated in the same manner as in other conventional reinforced concrete structures. Detailed analysis shall be made when large openings, of size greater than five times the wall thickness, are required. The arrangements for supporting the walls of a bin shall depend upon the layout, the outlet openings, positions of draw off conveyors and type of bin bottom, etc. For polygonal bins, columns shall normally be placed at the junctions of side walls. For circular bins the wall may be either extended up to the foundation level or stopped on a ring beam supported on a group of columns.

1.6 Reinforcement parameters

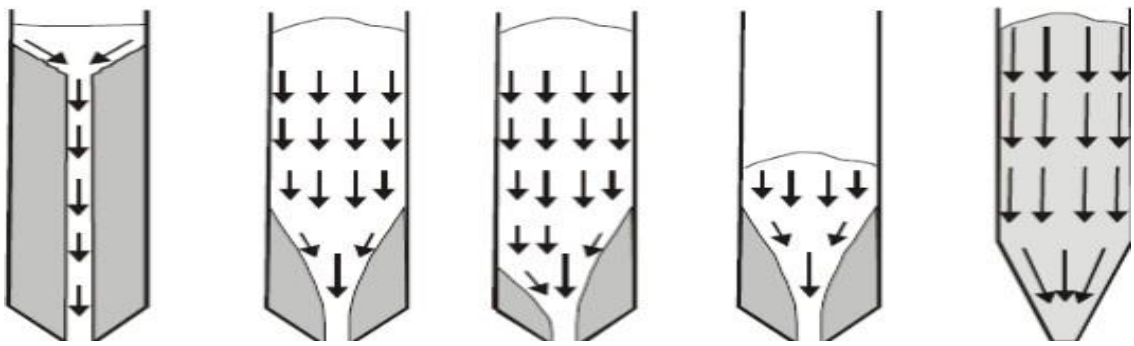
1.6.1 Circumferential reinforcement- The minimum circumferential reinforcement shall be 0.25 percent of cross-sectional area of the bin wall when deformed bars are used. When mild steel bars are used this shall be 0.3 percent of the cross-sectional area of the bin wall. Splices in bars shall be well staggered. The bars shall be at least 8 mm in diameter. Spacing of circumferential reinforcement shall not exceed 200 mm and bar diameter shall not be less than 8 mm when deformed bars are used and 10 mm when mild steel bars are used.

1.6.2 Vertical reinforcement- Vertical Reinforcement shall not be less than 0.2 percent of cross-sectional area of the wall for single bins or exterior walls of battery of bins, when deformed bars are used. For interior Walls of battery of bins its minimum value shall be 0.15 percent of the cross- sectional area when deformed bars are used. When Mild steel bars are used the vertical reinforcement shall be taken as 0.25 percent and 0.20 Percent respectively for the above cases. The minimum bar diameter shall be 10 mm when deformed bars are usedand 12 mm when mild steel bars are used are used.

The vertical reinforcement shall preferably be provided in two layers half near the inside and half near the outside face of the wall. If the reinforcement is provided in one layer, the spacing shall not exceed 225 mm and 300 mm depending upon the two cases of single bins orinternal walls of battery of bins and if the reinforcement is provided in two layers, the corresponding spacing shall be 450 and 600 mm. Deformed bars or cold twisted bars shall preferably be used for the reinforcement in bin walls to facilitate fixing of horizontal bars andoperation of sliding form-work Vertical construction joint shall not be allowed in the wall.
Horizontal construction joints shall be maintained at suitable spacing throughout as far as possible. A minimum clear concrete cover of 30 mm shall be provided for the reinforcement.

1.7 Flow pattern in silos

During emptying of the stored material from silo, various types of flow pattern have been observed, that may cause generation of extra stresses on silo walls. Some of them are shown below.



Funnel flow **Semi mass flow** **mass flow**

Figure 1.2 - types of flow patterns occurring in silo[4]

The physical properties of materials stored in silos and bunkers influence the flow ability of the material and the forces that the material applies to the silo walls and bottom. Obviously, those properties will vary from one material to another, but they may also vary within a supposedly uniform material. In materials of this latter type (coal is a good example) large variations of proper ties occur between materials from different sources or even in materials from a common source. Other properties that may influence flow ability or pressure include particle size and gradation (which affect moisture content), physical strength (which affects degree of compaction), cohesiveness, and shrinkage or swelling characteristics.

1.7.1 Effect of temperature variation

Daily temperature changes due to intense sunlight may cause accordion-like expansion and contraction of silo groups. Stresses due to this action can be large enough to cause wall concrete to crack. Seasonal temperature change can have a similar effect. Steel silos can failby daily thermal expansion and contraction while the material within becomes denser with each daily movement. Concrete roofs may also be affected by temperature: changes and gradient. If roof movement due to temperature change is not controlled, the roof may "walk away" from its original position and cause serious damage.

1.8 Causes of silo failure

Some of the major causes due to which a silo may get damaged or even collapse are mentioned below-

1- Design error

2- User error

3- Construction error

Design errors commonly involve inadequate pressures, buckling, improper details, or insufficient detail to guide the builder. Construction errors include dislocation, improper spacing, and omission of reinforcing, poor workmanship, and use of poor quality materials, non-proper joint design, too long pause between subsequent concrete filling, using vibrators inappropriate for steel bars diameter and for distances between them, touching by vibrator steel bars, too small or destroyed thermal insulation, destroyed moisture, chemical or thermal protecting coating, too few steel bars calculated shrinkage for shells wall, temperature field on the silo wall caused by storage grain, insolation and daily temperature variation, big temperature gradient across the wall. User errors include storing materials other than those for which the structure was designed and modifying the system to change the manner or rate of discharge, dynamic loads; self-induced vibrations; explosions; changes of flow patterns, failure due to improper maintenance, improper reaction to signs of distress.

1.9 Seismology

Earthquake or seismic analysis is a subset of structural analysis which involves the calculation of the response of a structure subjected to earthquake excitation. This is required for carrying out the structural design, structural assessment and retrofitting of the structures inthe regions where earthquakes are prevalent. Various seismic data are necessary to carry out the seismic analysis of the structures. These data are accessible into two ways viz. in deterministic form or in probabilistic form. Data in deterministic form are used for design of structures etc. whereas data in probabilistic form are used for seismic risk analysis, study of structure subjected to random vibration and damage assessment of structures under particular earthquake ground motion. Major seismic input includes ground acceleration/velocity/displacement data, magnitude of earthquake, peak ground parameters, duration etc.

Seismic Zone Factor	II	III	IV	V
Z	0.10	0.16	0.24	0.36

Table 1.2- Seismic Zone Factor Z [16]

The response of a structure is defined as the magnitude and distribution of the resulting forces and displacement is a system due to vibration. On the basis of severity of earthquake, our country is divided into 4 seismic zones. The intensity of earthquake is the measure of strength of shaking at a location during an earthquake. The intensity becomes weaker outward from the epicenter. Intensity is measured by Mercalli scale which is a 12-point scale while the magnitude is the measure of amount of strain energy released during an earthquake. It is measured by Richter scale which ranges from 0-9.

Seismogram is the graph showing the motion of the ground versus time. It is the record of the ground motion at a measuring station as a function of time. The response of a structure is measured in terms of displacement, velocity and acceleration. A graph plotted between acceleration of ground and time is called accelerogram. PGA is the peak ground acceleration which is maximum acceleration experienced by a particle on the ground. Following assumptions has to be made in the earthquake resistant design of a structure:

1- Earthquake causes impulsive ground motions, which are complex and irregular in character, changing in period and amplitude each lasting for a small duration. Therefore, resonance of the type as visualized under steady-state sinusoidal excitations will not occur, as it would need time to build up such amplitudes.

2- Earthquake is not likely to occur simultaneously with maximum wind or maximum flood or maximum sea waves.

3- The value of elastic modulus of materials, wherever required, may be taken as for static analysis unless a more definite value is available for use in such conditions.

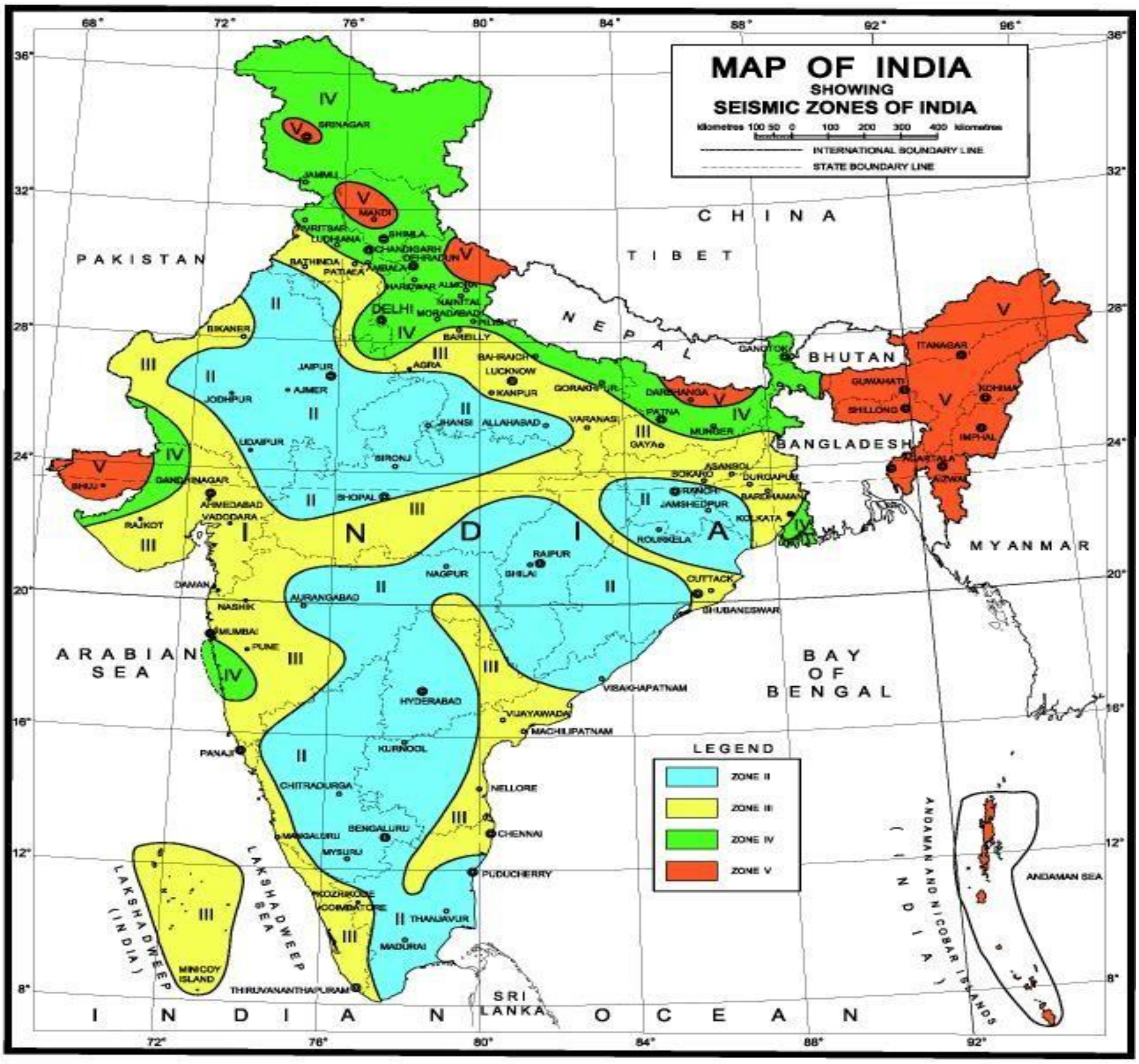


Figure 1.3- Seismic zones of India [16]

1.9.1 Types of Seismic analysis

1- Dynamic analysis

2- Static analysis

1.9.2 Dynamic analysis

Dynamic analysis is an analysis of the structure subjected to dynamic loads that change their magnitude and direction with respect to time. Loads such as wind load earthquake load, traffic, blasts, comes under dynamic loading. Inertia forces are developed in a structure when the dynamic loading is subjected to it. Response of a structure can be analyzed by dynamic analysis if load varies rapidly with respect to time.

1.9.3 Response Spectrum Analysis

It is a linear but dynamic method of analysis. In this approach, multiple mode shape of the building is taken into account. For each mode, a response is read from the design spectrum based on the modal frequency and the modal mass. They are then combined to provide an estimate of the total response of the structure using modal combination methods.

Response spectrum analysis calculates and combines model response from spectra curves using model superposition. The no. of modes to be used in the analysis for earthquake shaking should be such that sum of total modal masses of modes considered is at least 90% ofthe total seismic mass.

1.9.4 Base shear

Due to motion of ground during the earthquake maximum total lateral force acts at the baseof the structure is estimated in terms of base shear. Which is influenced by various factors like height, acceleration response of structure, its mass, natural period and soil conditions According to IS 1893 (Part I): 2016 the parameter base shear can be calculated using formula,

VB = Ah x W

Ah = (Z/2) x (I/R) x (Sa/g)

Where,

Z = Zone factor (ZONE II, ZONE III, ZONE IV, ZONE V)

I = Importance factor (It depends upon occupancy category of the building).

R = Reduction factor (It depends on type of lateral load resisting system used).

Sa/g = Average response acceleration coefficient. (It depends on type of rock or soil sites and also the natural period and damping of the structure

W = Seismic weight of the structure

Base shear primarily depends on following factors: -

- Condition of soil on the site
- Closeness to potential sources of seismic activity like geological faults.
- Probability of significant seismic ground motion due to earthquakes.
- Total weight of Building.

- Period of the vibration.

The approximate fundamental translational natural period Ta of oscillation in seconds shall be estimated by the following expressions:

a) Bare MRF building (without any masonry infill)

$$T_a = \begin{cases} 0.075h^{0.75} & \text{(for RC MRF building)} \\ 0.080h^{0.75} & \text{(for RC-Steel Composite MRF building)} \\ 0.085h^{0.75} & \text{(for steel MRF building)} \end{cases}$$

b) Buildings with RC structural walls

b) Buildings with RC structural walls:

$$T_a = \frac{0.075h^{0.75}}{\sqrt{A_w}} \geq \frac{0.09h}{\sqrt{d}}$$

c) All other buildings

$$T_a = \frac{0.09h}{\sqrt{d}}$$

Where,

h = height in (m) of building

Aw = total effective area ($m^{2)}$ of walls in first storey of building

d = base dimension of building at the plinth level

1.9.5 Drift

The word "Drift" can be defined as the lateral displacement of the structure, Storey drift is the slower and small movement of one level of a multilevel building relative to the level below. Inner storey drift is the difference between the floor and roof displacements of any given story as the building sways during the earthquake, marked by the story height, more is the storey drift will cause more damages to the structures, its value should not be beyond the limit0.004h, where (h) is height of the building.

1.9.6 Displacement Criteria

The maximum lateral deflection of the top of the stack like structure under all service condition, prior to the, application of load factor, shall not exceed the limit of :-

$D_{max} = 0.003h$

Where,

D_{max} = maximum lateral displacement h

h = Height of structure above the base

1.9.7 AboutSAP2000 software

Founded in 1975, Computers and Structures, Inc. (CSI) SAP2000 is recognized globally as the pioneering leader in software tools for structural and earthquake engineering. CSI's software is backed by more than four decades of research and development, making it the trusted choice of sophisticated design professionals everywhere. Each of these programs offers unique capabilities and tools that are tailored to different types of structures and problems, allowing users to find just the right solution for their work. SAP2000 is intendedfor use on civil structures such as dams, communication towers, stadiums, industrial plants and buildings.

1.9.8 Features of SAP2000 software

SAP2000 offers a single user interface to perform modeling, analysis, design, and reporting. The customizable SAP2000 interface allows users to define window layouts and toolbar layouts. Engineers have the ability to manipulate models with extreme flexibility with the useof dock able windows, floating forms and multiple views. From its 3D object-based graphical modeling environment, this intuitive interface allows you to create structural models quickly without long learning curve delays. Now you can harness the power of SAP2000 for all of your analysis and design tasks, including small day-to-day problem.

CSI software stores model data and other information in database tables which may be directly edited through interactive database editing. This powerful feature allows models to be developed quickly or edited. The frame element uses a general, three-dimensional, beam column formulation which includes the effects of biaxial bending, torsion, axial deformation, and biaxial shear deformations. SAP2000 has a built-in library of standard concrete, steel and composite section properties of both US and International Standard sections.

When seismic has been selected as the load type, various auto lateral load codes are available. Upon selection of a code, the Seismic Load Pattern form is populated with default values and settings that may be reviewed and edited by the user. SAP2000 will generate and apply seismic and wind loads automatically based on various domestic and international codes. SAP2000 also has a sophisticated moving load generator that allows users to apply moving loads to lanes on frame and shell elements.

Output and display options are intuitive and practical. Finalized member design, deformed geometry per load combination or mode shape, moment, shear, and axial-force diagrams, section-cut response displays, and animation of time-dependent displacements outline a fewof the graphics available upon conclusion of analysis. SAP2000 automatically generates reports for the presentation of images and data. Built-in and customizable templates are available to users for specialized formatting

CHAPTER-2

LITERATURE REVIEW

2.1 Review of research done in past

Some of the relevant literature on the topic “To study the effect of seismic loads on concrete silos structures” are covered here that deals with the seismic performance, stability parameters and response of concrete silos. Some of those are discussed below: -

1. **Y. Di, M.-W. Yuan** **[1]** (2001): The elastic stability of reinforced concrete silo shell roof is analyzed by using finite-element model. The elastic critical buckling loads of the shell roofare calculated. Based on the limit analysis theory, the method for calculating the ultimate loadof silo shell roof is also presented. The analyses of practical applications indicate that the reinforced concrete silo shell roof in common practical use is always elastic stable, and the limit analysis theory should be used to assess the design proposal.

2. **G. E. Blight** (2002) : This paper states that while designing reinforced concrete silos, it is common to assume that the concrete carries no tension and that hoop tension in the silo wall is carried entirely by the hoop reinforcing. In fact, the concrete may carry a considerable proportion of the hoop tension when the silo is filled for the first time, and the sharing of load between steel and concrete may persist through many years of continuous service, with repeated filling and emptying of the silo. The paper presents four case histories of strain measurements made on reinforced concrete silos that illustrate the long-term sharing of load between steel and concrete in silo walls during service.

3. **Mohamed T. Abdel-Fattah a, Ian D. Moore b, Tarek T. Abdel-Fattah[2]** (2005): This paper introduces a finite-element solution for simulating the filling process of ground-supported concrete silos filled with saturated granular material. An elasto-plastic ax symmetric finite-element model is used to represent both the granular material and the concrete silo. The interaction between the two materials is modeled using interface elements to allow for relative movement. The filling process is idealized via a multi-stage numerical technique capable of representing both undrained and drained conditions for the granular material.

The effects of the relative stiffness between the foundation and wall are examined,as are the boundary conditions at the top of the structure.

4. **Istvan Bodi, kalman Koris** (2006): A square shaped reinforced concrete silo structure has been analyzed by the Department of Structural Engineering (BUTE). The structure was analyzed on a 3D finite element model. The concrete strength of the structure was lower than designed and there were some problems with the structural build-up as well, therefore an appropriate strengthening strategy was developed. Due to the massive machinery, there was no space enough for complementary back-up, therefore a steel shoulder of low space demand has been designed to support the floor under the Breakstone storage. It is important to notice that the source of the problems was not only the lower concrete strength but application of a construction procedure without rational control.

5. **F. NATEGHI, M.YAKHCHALIAN[4]** (2011) : in this paper we have used ABAQUS finite element package for modeling of earthquake effect on a reinforced concrete silo, reinforced concrete silo walls are modeled by shell elements and their nonlinear behavior is considered by concrete damaged plasticity model, seismic behavior of granular material inside silo is highly nonlinear and requires a complex nonlinear description of the granular material, the behavior of granular material is incrementally nonlinear even at low strains. The hypo plasticity theory describes the stress rate as a function of stress, strain rate and void ratio. It can model the nonlinear and inelastic behavior of granular materials due to its rate-type formulation. Granular material inside silo is modeled by solid elements and its nonlinear behavior is considered with a hypo plastic constitutive model, for modeling of interaction between silo walls and granular material, surface to surface contact with coulomb friction law is considered between silo walls and granular material. After modeling, the behavior of reinforced concrete silo under earthquake excitation is compared with a model without considering granular material-structure interaction.

6. **Guang Lin Yuan, Lu Dan Tian** (2011) : Accidents of the cement manufacturers reinforced concrete silo structures frequently occurred currently in China, because of quality problems, causing enormous losses. The collapse status of a cement raw meal silo is investigated. Combined with the test results of the location and spacing of silo wall’s reinforcing bars, concrete strength, cracks and defects, the reasons for collapse of silo wall are analyzed.

Design recommendations for concrete silo structures are made. This can givereference to reinforced concrete silo structure design and construction in the future.

7. **Islam M. Ezz El-Arab**[(5)] (2014): This paper presents the characteristics of the flow pattern and wall pressures observed during filling and emptying of cylindrical silo during gravity discharge. In order to ensure the accuracy for modified finite element model that is presented in paper; it is verified with other's experimental results. Under different three types of earthquake ground excitations; Al-Aqba, 1995, Northridge, 1994, and El-Centro, 1940; the paper is dissected the silo discharge phenomenon; which has a stress peak during the dynamic discharge of the silo. Caused by that fact, the modeling of silo should be taken this phenomena effect in the simulation. Especially, this phenomenon has great effect on the silo mass distribution which reflects on the flow of granular material during filling and discharge.

8. **Hamdy H.A. Abdel-Rahim** (2014) : Silos are special structures subjected to many different unconventional loading conditions, which result in unusual failure modes. . The earthquake response of silo structures for the storage of bulk solids differs for elevated silos and silos supported directly on the ground. This paper is concerned with the earthquake response of these structures, which has received little attention to date. A cylindrical silo walland bulk solid is modeled by three-dimensional finite solid l elements. The interaction effect between the silo wall and bulk solid is taking account by using the nonlinear approach proposed by Duncan and Chang. The seismic responses of the elevated wheat silo such as topdisplacement, normal forces, shearing forces and bending moments in silo support have been assessed for earthquake records.

9. **Y. Gong, Y. Li, L. Wang** (2014) : In order to analyze the dynamic characteristics of a group of reinforced concrete silos supported by columns, the computational model of the structure is simplified into a combination of Timoshenko beams with variable cross-sections resting on a semi-infinite elastic body. The deflection of the neutral surface and the cross- sectional rotation around the neutral axis of the combination are chosen as two basic unknown functions. By applying the Hamilton principle, the motion equations for the free vibration of the combination are then translated into a set of ordinary differential equations composed by two unknown functions, which can be solved by an ordinary differential equation solver (ODE solver). Therefore, the natural frequencies and mode shapes of the combination are obtained. The comparative study demonstrate the efficiency and precision of the numerical method.

10. **Ayşegül Durmuş, Ramazan Livaoglu[6] (**2015): The purpose of this study is the evaluation of dynamic behavior induced by seismic activity on a silo system, containing bulk material, with a soil foundation. The interaction effects between the silo and bulk material, as well as the effects produced between the foundation of the silo and the soil, were taken into account. The results, from the presented approximation, were compared with a more rigorous obtainment method. Initially, the produced simplified approximation, with elastic material assumption for the grain, could determine the pressures on the dynamic material along with displacements along the height of the silo wall and base shear force, etc., with remarkable precision.

11. **N. Kuczyńska, M. Wójcik, J. Tejchman** (2015): The paper presents 3D numerical analysis results on the effect of bulk solid on strength and stability of metal cylindrical silos with corrugated walls (without stiffeners) during filling. The behavior of two bulk solids (dry sand and wheat) was described with a hypo plastic constitutive model. Non-linear FE analyses with both geometric and material non-linearity were performed. The numerical results were compared with the Eurocode formulae. The strengthening effect of the stored solid, wall thickness, solid granular hardness, initial void ratio of solid and wall friction angleon buckling strength was investigated. The major contribution of the paper is the quantitative estimation of the effect of the bulk solid stiffness on the silo stability and wall stresses.

12. **R. Livaoglu, A. Durmus** (2015): In order to estimate the distribution, as well as the magnitude, of dynamic material pressures on ground-supported silos a simplified seismic analysis procedure was utilized. In addition to a simplified model for the seismic analysis of a silo–bulk material system being utilized; a three-dimensional finite element model was also incorporated. Using the finite element method, a more realistic representation of the structure is possible. Moreover, the finite element method also takes into consideration contact problems between the bulk material and the silo wall, which results in easier analyses. Bulk material–silo wall interaction considerably affects the seismic behavior of silos. It is clearly seen from the findings of the analytical and numerical analyses, that consideration of the contact mechanism is quite significant both for determining the behavior of the system and

magnitudes of the responses. It should be noted that using the analytical method as proposed in Eurocode, the dynamic material pressure for squat silos can be underestimated, but the results for slender silos are stronger.

13. **Marek Maj** (2016): This paper presents some problems connected with causes of reinforced concrete silos failure. Some reasons of appearance of horizontal and vertical cracks as temperature, pressure of stored material, live loads e.g. wind, dynamic character of wind, moisture, influence of construction joints, thermal insulation, chemistry active environmental etc. reduce the carrying capacity of the walls of the silos and causes lower the state of reliability. Horizontal and vertical cracks can cause corrosion of concrete and steel bars, decreasing stiffness of contraction. Local and global imperfections of concrete shells are increasing according to greater number of cracks. Taking into account these facts, reducing ofstrength parameters reduce the service life of the whole reinforced concrete structure causing failure status.

14. **KRISHNA KHARJULE, CHITTARANJAN NAYAK**[7] (2016): This review article finds that as the height increases, they are more vulnerable to earthquake. Earthquakes can also cause damage in the upper portion of the silo if the material contained can oscillate inside the silo during the earthquake. The walls of different type of silos are subject to earthquake loads from the stored mass, and these may substantially exceed the pressures from filling and discharge. The elevated silos response is highly influenced by the earthquake characteristics and is depending on the height to diameter ratio, hence there is need to do seismic analysis of such type of tall and slender structure. In this paper, circular elevated siloswith different stored material are considered for study. There are three methods used for calculation of pressure on silo Janssen Method, Airy Method and Reimbert Method.

15. **Changdong Zhou,Lingkai Meng, Xiaoyang Zhang**[8](2016) : As a special shell structure, silos are used in storing a wide range of multitudinous granular materials. However, seldom have researchers assessed seismic vulnerability of the reinforced concrete (RC) silo. This paper aims at studying the seismic vulnerability assessment of a silo. After discussing the validation of the hypoplastic theory, the numerical model considering granular material-structure interaction is developed by means of the ABAQUS software. And the numerical simulation results are compared with the experimental data obtained from a shaking table test

discussed in order to confirm the validation of the numerical model, which is used to study the seismic vulnerability of the RC silo. Then the seismic fragility assessment of the selected RC silo is performed using the incremental dynamic analysis.

16. **Alper Kanyilmaz, Carlo Andrea Castiglioni**[9] (2017): Industrial silos are used for storing a huge range of different materials. This paper shows the feasibility of the seismic isolation solution on a typical case study. Seismic vulnerability of an existing industrial steel silo system has been investigated, and a retrofitting solution has been proposed making use of the curved surface single sliding pendulum devices. Incremental dynamic analysis method has been used to compare the performance of the original and the retrofitted solutions. Structural benefits of the seismic isolation solution have been quantified in terms of inelastic deformations, base shear, inter-story drifts and isolator displacements.

17. **Luca Pieraccini, Michele Palermo, Silvestri Stefano, Tomaso Trombetti** [10] (2017): silos frequently fails during large earthquakes, as occurred during the 1999 Chi, Taiwan earthquake. The fact indicates that actual design procedures have limits and therefore significant advancements in the knowledge of the structural behavior of silo structures are still necessary. The present work presents an analytical formulation for the assessment of the natural periods of grain silos. The predictions of the novel formulation are compared with experimental findings. The silo is modelled as an equivalent shear-flexural cantilever beam with an applied mass equal to the mass of the silo structure plus the mass corresponding to the portion of the ensiled mass activated during the earthquake ground motion. Doing so, a fully analytical formula has been derived and can be easily implemented even in a simple excel spreadsheet for the prediction of the natural periods of grain-silos.

18. **Christoph Butenweg 1, Julia Rosin 1, and Stefan Holler**[11] (2017): Silos generally work as storage structures between supply and demand for various goods, and their structural safety has long been of interest to the civil engineering profession. The analysis of silos can be carried out in two different ways. In the first, the seismic loading is modeled through statically equivalent loads acting on the shell. Alternatively, a time history analysis might be carried out, in which nonlinear phenomena due to the filling as well as the interaction between the shell and the granular material are taken into account. The paper presents a comparison of these approaches. The model used for the nonlinear time history analysis considers the granular material by means of inter granular strains approach for hypoplasticity theory.

The interaction effects between the granular material and the shell is represented by contact elements. Additionally, soil–structure interaction effects are taken intoaccount.

19. **R. E. Rowe** (2017) : The paper describes a series of tests carried out to determine the cause of cracking in a reinforced concrete silo used for storing cement. . The cause of cracking was a combination of the effects of pressure in excess of those designed for, large temperature differentials through the walls of the silo, and a deficiency in reinforcing steel. From the results obtained it is clear that Janssen's theory for the pressure exerted by granular materials on the walls of a container is inapplicable to cement. An alternative method of determining the pressures, based upon the experimental results, is put forward. The temperature differential through the walls was about 33°C during the tests and indicates that this factor must be considered in the design of a cement silo.

20. **Hisham Jahangir Qureshi, Zahid Ahmad Siddiqi** [(12)] (2018): In this study, analysis and design procedures are summarized and presented in a simplified form to make sure the efficient practical design applications of reinforced concrete silos. These structures are highlyvulnerable when subjected to intense seismic forces. The silo was designed using given design procedure and modeled using FEM-based computer package. All of the reinforced concrete silos were subjected to gravity, wind and seismic forces. The comparison of tangential and longitudinal forces, bending moments, shear forces and reinforcement ratios ofdifferent parts of silos have shown a fair agreement with the FEM model results. It motivates to use the proposed design procedure for an efficient design of reinforced concrete silos.

21. **E.H. Lahlouh, P WALDRON, N.J. Woodman (**2019**)** : An assessment of the performance of a large multicellular concrete silo is described which involved both field monitoring and structural analysis. The structure was instrumented with a large number of strain gauges embedded within both in situ concrete external walls and precast concrete slab elements forming the internal walls. Results obtained from short-term load tests were compared to predictions from a detailed finite element analysis which provided information on the complex interaction between the in situ and precast panel walls in which beneficial compressive membrane stresses were found to develop.

22. **Lakshmi E Jayachandran, Nitin .B, Pavuluri Srinivasa Rao** (2019) : Design and development of low-cost farm silos call for a strong understanding of its structural been developed and the grain filling in progressive layers simulated in the ANSYS® software, FEM predicted non-uniform stress distribution due to the bulk grain at the silo bottom. The numerical approach could also identify the localized peak pressures and stress distribution patterns within the grain layers, which is usually beyond the scope of analytical techniques. Possible reasons for fluctuations in stress patterns are discussed in detail. The study unveiled the intricacies involved in the FEM and the analytical outcomes while predicting the stresses in small and medium scale silos intended for use on farms.

23. **Hemesh J, Surya Prakash, Adlin Rose** (2020): Silos are the structures meant for storing materials like food grains, cement, coal, ore, crushed stone, gravel, clinker etc., in large quantities. In this project planning, analysis, structural design and has been done for a concrete silo based on all Indian standard code for practice. Detailing drawings pertaining to the structural design of market building are presented. All the structural members like slabs, Ring beams, columns, hopper and footings are designed using Indian Standard code IS 4995 PART I & II, IS 456-2000 and IS 875.The structural components are designed by limit state method. Materials were used as specified by National Building Code. Concrete M20 grade and Fe415 steel bars were considered for all the design. Cylindrical walls are 120 mm thick. It was found in the analysis that the members were safe in carrying the design loads according to limit state method.

24. **Chrysanthos Maraveas** [(13)] (2020): The review article investigated failure, design issues, repair and strengthening of reinforced concrete (RC) silos, primarily in agricultural set-ups. The durability of RC structures was influenced by the nature of the bulk solids, materials used in the reinforcement of the structures. fiber-reinforced polymers (FRP) have better mechanical properties (tensile strength, elastic modulus, and Poisson’s ratio) and are not corroded. Additionally, there are limited scalable and facile methods for commercial production. The low ductility elevates the risk of brittle fracture in external pre-stressing concrete repair/strengthening. However, the continued utilization of steel in the reinforcement of silo structures poses considerable structural challenges considering the susceptibility to environmental degradation and corrosion.

25. **Qikeng Xu, Hao Zhang, Qiang Liu, Lumin Wang[14]** (2020) : The main objective of this research is to explore the seismic performance of the group silos through the shaking table tests and the finite element analysis. The 1/16 scaled model of reinforced concrete silos supported by supporting wall was designed and constructed. The shaking table tests were carried out with gradually increasing table-input acceleration amplitudes. The dynamic characteristics, seismic responses, cracking patterns and failure mechanism of the model under empty and full conditions were analyzed. The finite element model was established and verified by experimental results. This article is aimed to provide guide for engineering design of group silos.

2.2 Inference

On the basis of above literature review, following major inferences can be drawn

1- Flexural cracks have developed in the lowest part of silo walls near the symmetry plane and shear cracks have developed in the height of silos.

2- The analysis of dynamic behavior shows that the displacement effects and base shear force generally decrease when soil was softer.

3- The elevated silos response is highly influenced by the earthquake characteristics and is depending on the height to diameter ratio.

4- The lateral restraint at the top of the wall has negligible effect on the forces that develop in the wall, regardless of foundation rigidity.

5- The seismic response of a structure depends on relationship between fundamental frequency of the system and the frequency content of the excitation.

6- If the base is resting on loose soil then it would be either densified or stiffened with admixtures, soil- cement piles or stone columns.

7- With the advancement of Fiber reinforced polymer, they have shown better strength, durability, crack resistance, toughness and are not corroded. So it can provide better option as an admixture in the concrete for silo for have overall better seismic performance.

2.3 Problem Statement

The complex nature of stresses resulting from seismic activity must be analyzed through numerical methods software such as SAP2000.The various geometric constraints of silos and the properties of stored material are important factors to be considered. These can be considered easily in the analysis software

2.4 Research Gap

There has not been much work done on the modeling and analysis of silo with different materials and compare them with reinforced cement concrete silos.

The results of different of different types of concrete needs to be compared so as to get the information of seismic performance of silo.

2.5 Objective

To study the comparative seismic performance of concrete silos in terms of displacement, base shear on the basis of following types of concrete:

- Conventional concrete of M40 grade and M40 mixed with glass fibers.
- Conventional concrete of M30 grade and M30 mixed with glass fibers.

CHAPTER 3

METHODOLOGY

3.1 Modeling- The entire analysis has been done on Sap2000 software which is preferred forseismic analysis of complex structures. In this section, first select the units, then go to file menu, select storage structures (Silo), then in material defining select concrete, then enter the dimension of silo and provide column to silo with suitable reinforcement with detailing.

3.2 Loadings

1) 1.5DL
2) 1.5 DL +1.5 LL
3) 1.2 DL + 1.2 LL + 1.2 EQx
4) 1.2 DL + 1.2 LL + 1.2 EQy
5) 0.9 DL + 0.9 LL
6) 0.9 DL + 0.9 EQx
7) 0.9 DL + 0.9 EQy

Above types of load combination has been considered with partial factor of safety. The analysis will be done for maximum value of factored load combination after applying the factor of safety as per IS 1893:2016 and IS 456:2000. The maximum value of above load combination comes for 1.2DL+1.2LL+ EQx. Horizontal and vertical acceleration is calculated using the seismic data of soil, zone factor etc.

3.3 Simulation and Analysis- the Mode of Analysis is Response spectrum Analysis (Complete Quadratic Combination).The analysis will be done based on the finite element methodology of the software. Here the result is displayed in the nodal form of silo model like shell stress, displacement etc. which can be transferred into tabular form in MS excel.

3.4 Result- The result can be displayed in MS excel through show table option. The values of Base reaction, element forces, joint, modal participation factor, response spectrum modal information, joint velocity, and joint acceleration can be viewed in tabular form and important findings can be extracted from the result.

3.5 Conclusion- Useful and constructive conclusion can be drawn on the basis of the above analysis which can prove to be helpful for research community and the researchers who want to contribute in this interesting and much coveted area of research.

Geometric properties of silo

Height of silo	22 m
Diameter of shell	6 m
Diameter of conical hopper	2 m
Height of conical hopper	4 m
Height of hopper above ground level	5 m
Total height of column	9 m
Reinforcement in column	8 rebar's of 20 mm diameter
Size of column	600 mm (circular)
Thickness of shell	300 mm

Seismic Data

Zone, Z	IV
Zone factor	0.24
Importance factor, I	1.5
Soil Type	Type II (Medium soil)
Damping ratio	5 %
Response reduction factor, R	5 (SMRF)

Loading Details

Dead load	Self-weight
Load of stored material	coal of density 10.4 KN/m3
Earthquake load	As per I.S. 1893:2016

Material property

Grade of concrete	M40,M30, M40 mixed with glass fibers, M30 mixed with glass fibers

Grade of steel	Fe 500
Concrete Density	25 KN/m^3

M40 GFRC Property

Modulus of elasticity, E	72 GPa
Poisson’s ratio	0.24
Coefficient of thermal expansion	10.7 x 10-6/C
Compressive strength	40 N/mm2
Shear Modulus, G	29 GPa

Figure 3.1 - 3D view of proposed model of silo

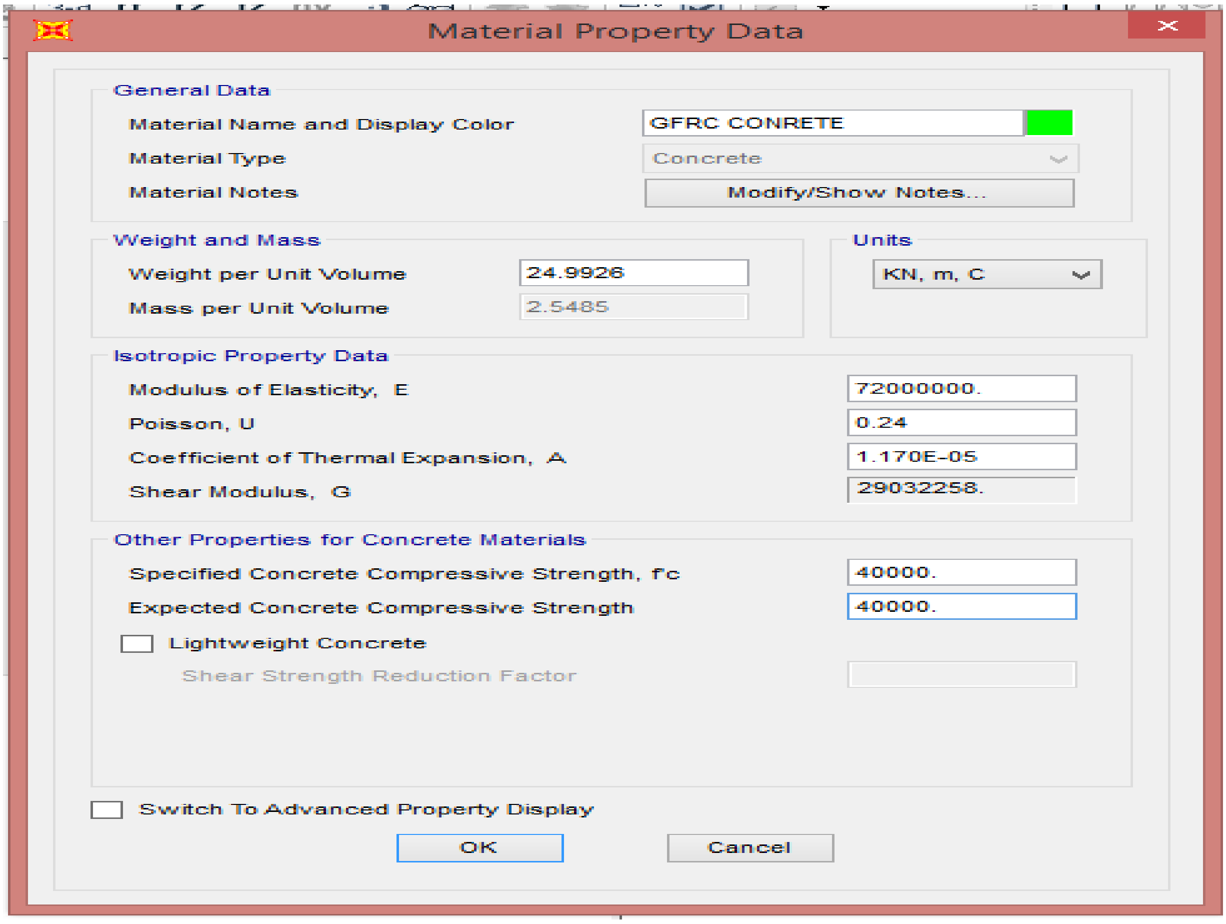


Figure 3.2 – Material property details of concrete mixed with glass fiber

Figure showing material property data of M40 concrete mixed with glass fibers. Fiber reinforced concrete is used to increase the modulus of elasticity which increases tensile strength and toughness of concrete. Here, Glass fibers is added as an admixture to M40 grade concrete that reduces crack width and improves ductility. Glass fibers involve use of short discrete randomly distributed fibers within the concrete mix. Modulus of elasticity is defined as the ratio of direct stress to direct strain. If the modulus of elasticity of materials is high then its stiffness will also be high and it will be resilient and show less deflection. Poisson ratio is ration of lateral strain to longitudinal strain. Its value is negative as the two strains have different direction. Depending upon the geometry and type of material (Homogenous, isotropic, anisotropic etc) its value ranges from 0.2 - 0.3, here Poisson ratio is taken as 0.24 likewise coefficient of thermal expansion is defined as the fractional increase in length per unit rise in temperature. GFRC has lesser coefficient of thermal expansion than conventional concrete. Therefore it will be in good compatibility with reinforcement under high thermal stresses. Shear modulus is the measure of rigidity of the body; it is given by the ratio of shear stress to shear strain. Its unit is same as shear stress N/m2. Hence above figure gives us details about the material property data.

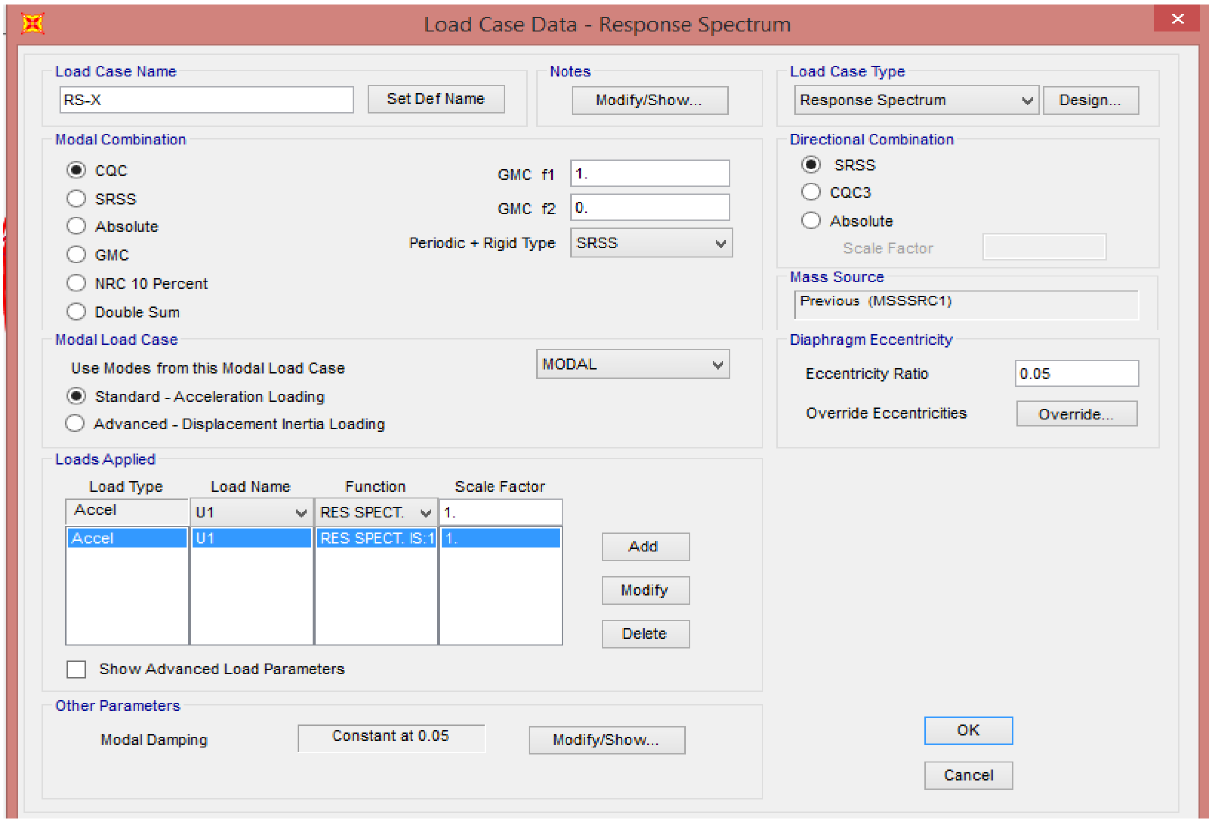


Figure 3.3 - Load case details

Figure showing loading case data. It indicates that analysis is being done by response spectrum method. Modal combination is CQC which stands for complete quadratic combination. Scale factor is 1; loading condition is standard acceleration loading. Damping factor is taken as 5%. The mass source data is the mass of the structure i.e. self weight as well as additional mass due to surface load usually DL+LL. This software has 3 ways to define mass source.

1. Element mass source: Defines mass using mass per unit volume of materials defined. And also considers additional loads like machinery load and live loads.

2. Additional mass: It includes loads like cladding

3. Specified mass: when we select this option only selected load patterns are considered for calculations of mass of structure.

Diaphragm eccentricity ratio is 0.05; load case type is response spectrum analysis which is a prevalent method to estimate the structural response to short, nondeterministic, dynamic events. It is a linear dynamic statistical analysis method which measures the contribution fr4om each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure.

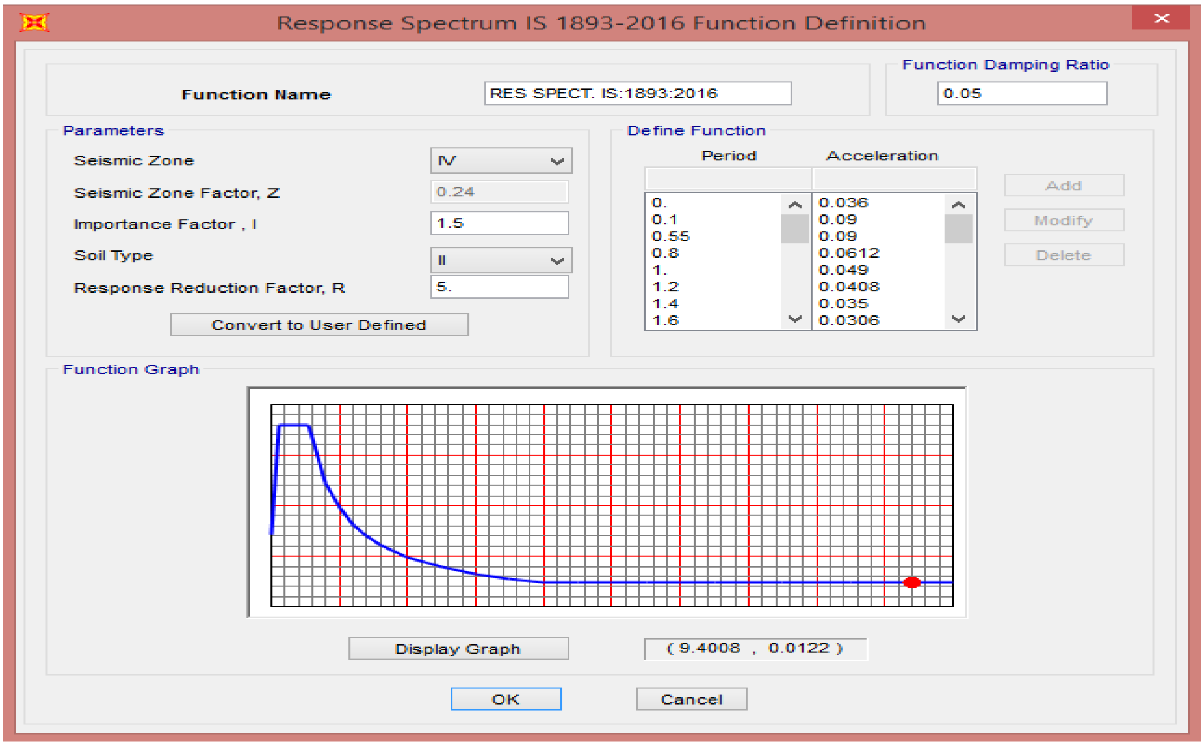


Figure 3.4 – Response spectrum function details

Figure shows response spectrum function definition of time period and acceleration along with seismic parameters. It gives information about the different seismic parameters which govern the horizontal seismic acceleration. On the basis of severity India is divided into 4 seismic zones namely II, III, IV, V. Zone V is the most vulnerable zone where earthquakes of high intensity have occurred in the past. The building importance factor, provided by the seismic codes, is a multiplier that increases the design loads of structures based on the occupancy types. The soil type may soft, medium and hard depending upon strength and stiffness of soil. Here medium soil (II) is considered for analysis. Either simplified method (that is, equivalent static lateral force method) or the dynamic response spectrum modal analysis method is recommended for calculating the seismic forces developed in such structures. Site spectra compatible time history analysis may also be carried out instead of response spectrum analysis. Design basis earthquake (DBE) for a specific site is to be determined based on either: (a) site specific studies, or (b) in accordance with provisions ofIS 1893 (Part 1). Structures in Category 1 shall be designed for maximum considered earthquake (MCE) (which is twice of DBE). Structures in Category 2, 3 and 4 shall be designed for DBE for the project site. The soil structure interaction refers to the effects of the supporting foundation medium on the motion of the structure.

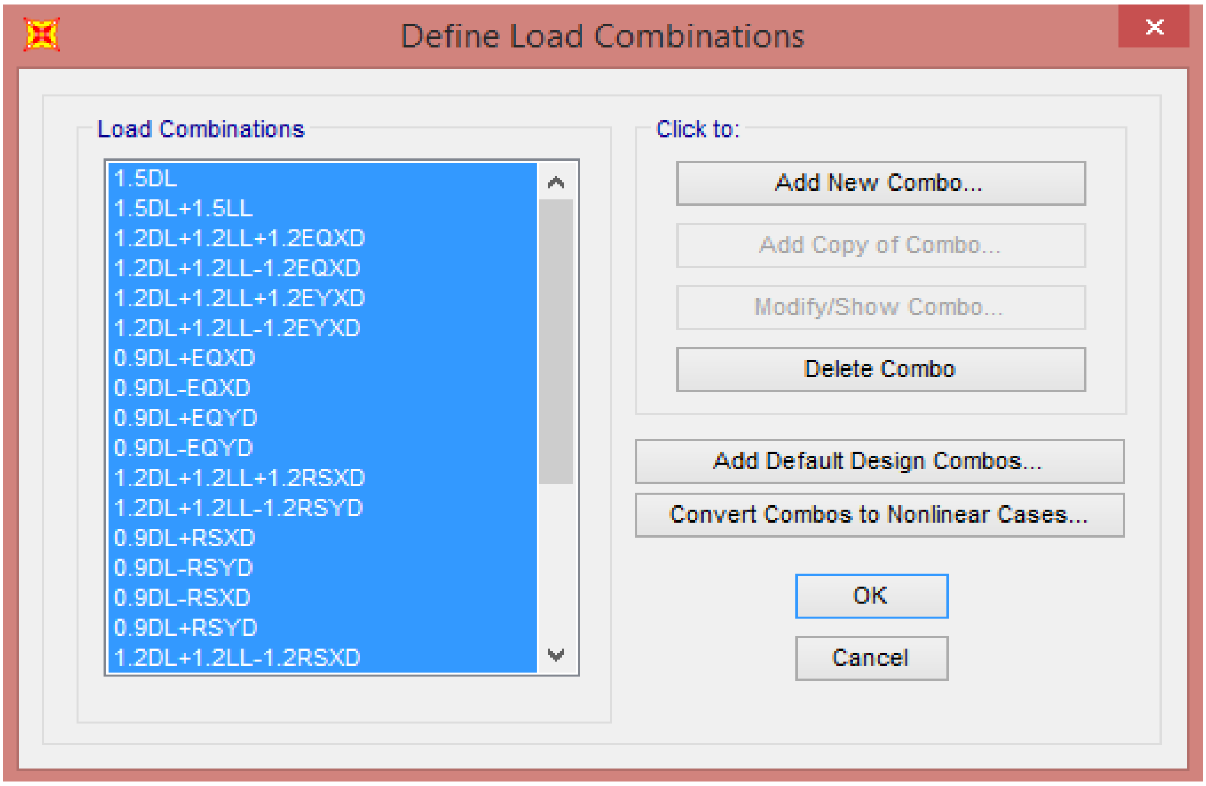


Figure 3.5- Load combination details

Figure showing the load combinations along with partial factor of safety. When earthquake forces are considered on a structure, the response quantities due to dead load, live load and design earthquake load shall be combined as given in the figure. The maximum value fromthe above combination will be chosen for the analysis. For limit state of collapse 1.5 and 1.2is considered as partial safety factor and for limit state of serviceability 0.9 is considered as partial safety factor. When responses from the three earthquake components are to be considered, the response due to each component may be combined using the assumption that when the maximum response from one component occurs, the responses from the other, two components are 30 percent of the corresponding maximum. All possible combinations of the three components (EL_x, EL_y, and EL_z) including variations in sign (plus or minus) shall be considered. Thus, the response (EL) due to the combined effect of the three components can be obtained on the basis of SRSS, that is

$$EL = \sqrt{(EL_x)^2+(EL_y)^2 + (EL_z)^2}$$

For structures under Category 1, which are designed under MCE and checked under DBE (Design Basic Earthquake), all load factors in combination with MCE (Maximum Considered Earthquake) shall be taken as unity.

CHAPTER-4

RESULT AND DISCUSSION

The maximum lateral displacement of the top of silo under all factored loads shall not exceed limit of 0.003h where 'h' is height of structure above base. Graph showing displacement (mm) with respect to Height of silo (m) in X- direction. It is clear that M40 GFRC is showinglesser displacement with respect to M40.

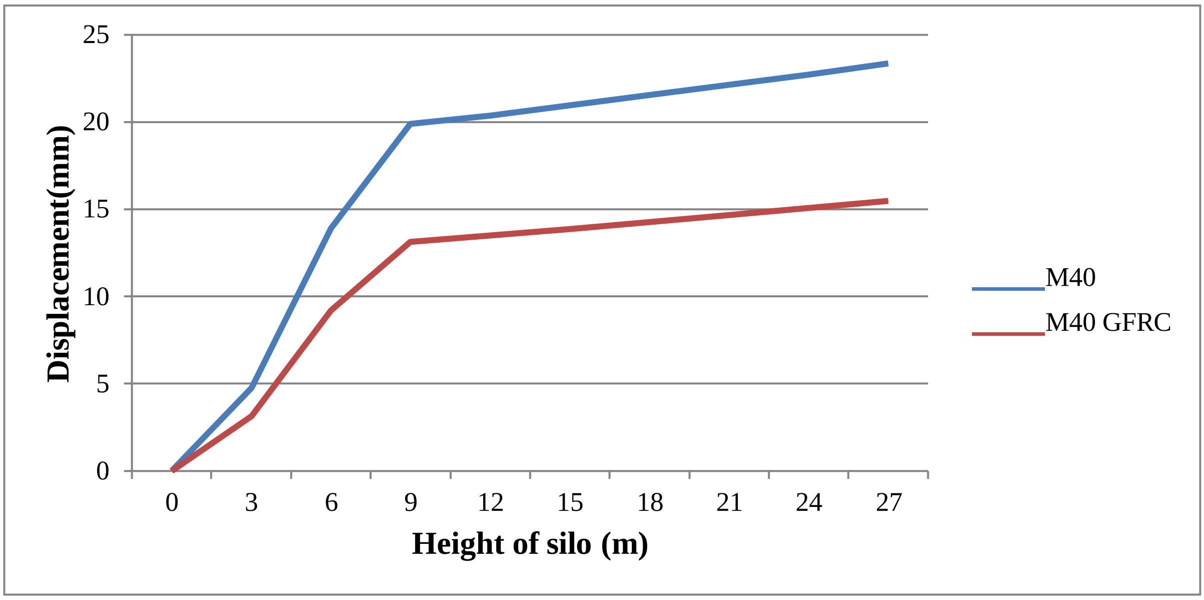


Figure 4.1 - Graph showing displacement in X direction

Height (m)	Displacement in M40 (mm)	Displacement in M40 GFRC (mm)
0	0	0
3	4.7539	3.1559
6	13.8882	9.2094
9	19.8698	13.1474
12	20.3807	13.4952
15	20.9566	13.8772
18	21.5401	14.2681
21	22.1302	14.6655
24	22.7311	15.0698
27	23.3566	15.4826

Table 4.1 - showing values of Displacement in X direction

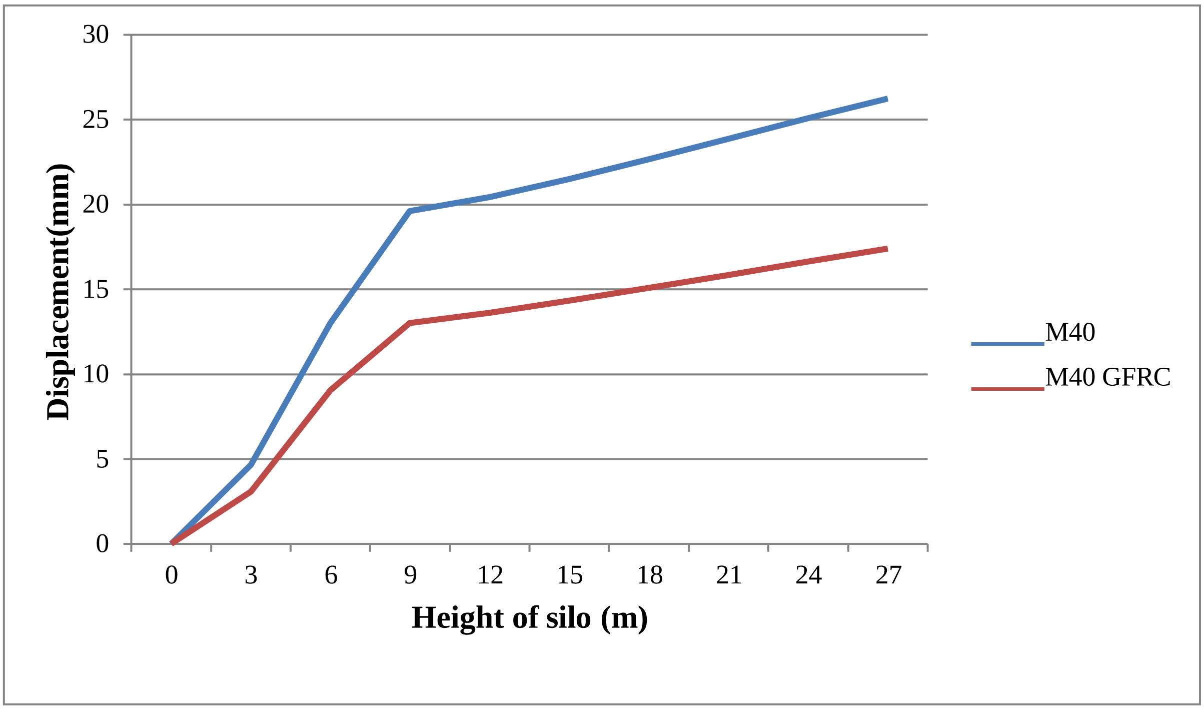


Figure 4.2 - Graph showing displacement in Y direction

Graph showing displacement (mm) with respect to height of silo (m) in Y-direction. It is quite visible that conventional M40 is showing more displacement in comparison to M40 GFRC. The introduction of Fiber reinforced polymer concrete is advantageous as it increases modulus of elasticity and toughness and reduces deflection and crack width. It involves the use fiber threads of different materials like steel fiber, glass fiber, polyethylene fiber etc. in certain calculated amount so that it enhances the performance of the structure.

Height (m)	**Displacement in M40 (mm)**	**Displacement in M40 GFRC (mm)**
0	0	0
3	4.6467	3.0803
6	13.0171	9.0268
9	19.6094	13.0022
12	20.4401	13.6060
15	21.5191	14.3231
18	22.6819	15.0817
21	23.8716	15.8548
24	25.0713	16.6339
27	26.2436	17.3996

Table 4.2 - showing values of Displacement in Y direction

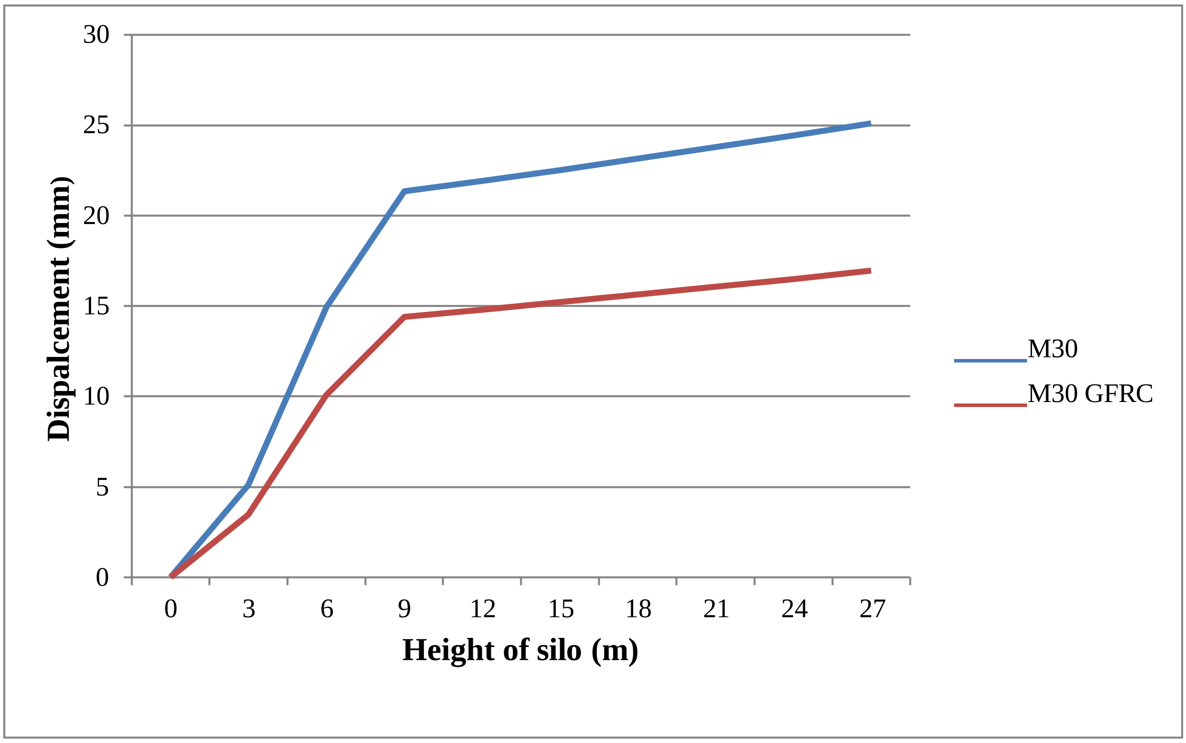


Figure 4.3 - Graph showing displacement in X direction

The maximum lateral displacement of the top of silo under all factored loads shall not exceed limit of 0.003h where 'h' is height of structure above base**.** Graph showing displacement (mm) with respect to Height of silo (m) in X- direction. It is clear that M30 GFRC is showinglesser displacement with respect to conventional M30. Hence the seismic vulnerability of M30 GFRC is lesser as its displacement are within the recommended limits. So, it is safer to use M30 GFRC rather than conventional M30 for better ductility and performance.

Height (m)	**Displacement in M30 (mm)**	**Displacement in M30 GFRC (mm)**
0	0	0
3	5.1068	3.4563
6	14.9224	10.0876
9	21.3591	14.4065
12	21.9047	14.7854
15	22.520	15.2040
18	23.1496	15.6313
21	23.7818	16.0659
24	24.4258	16.5079
27	25.0977	16.9606

Table 4.3 - showing values of Displacement in X direction.

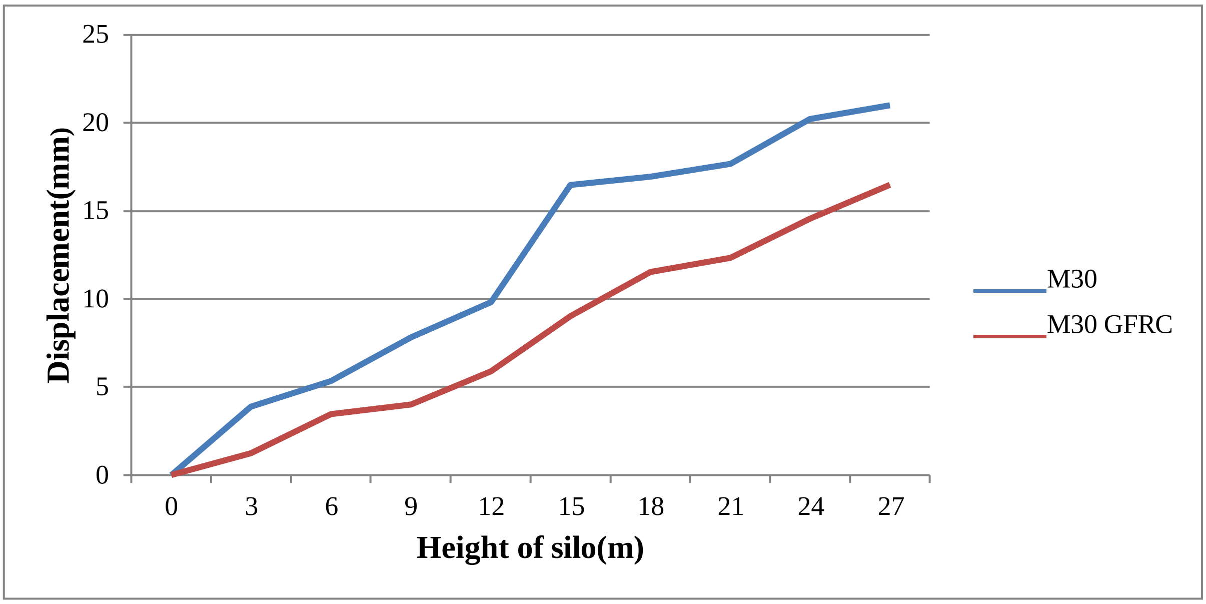


Figure 4.4- Graph showing displacement in Y direction

Graph showing displacement (mm) with respect to height of silo (m) in Y-direction. It is quite visible that M30 is showing more displacement in comparison to M30 GFRC. Conventional concrete may develop cracks due to plastic shrinkage, drying shrinkage and change in volume of concrete. Fibers help to improve post peak ductility performance, fatigue strength, impact strength. GFRC is better suited to minimize cavitation's/ erosion damage in structures. Fiber length up to 35 mm is used in spray applications and 25 mm lengths are used in premix applications. Fiber content ranges between 0.5% - 2% by volume.

Height (m)	Displacement in M30 (mm)	Displacement in M30 GFRC (mm)
0	0	0
3	3.8926	1.2355
6	5.3452	3.4620
9	7.8052	4.0096
12	9.8272	5.8842
15	16.4897	9.0342
18	16.9028	11.5328
21	17.6741	12.3347
24	20.2318	14.5628
27	21.0015	16.4821

Table 4.4 - showing values of Displacement in Y direction

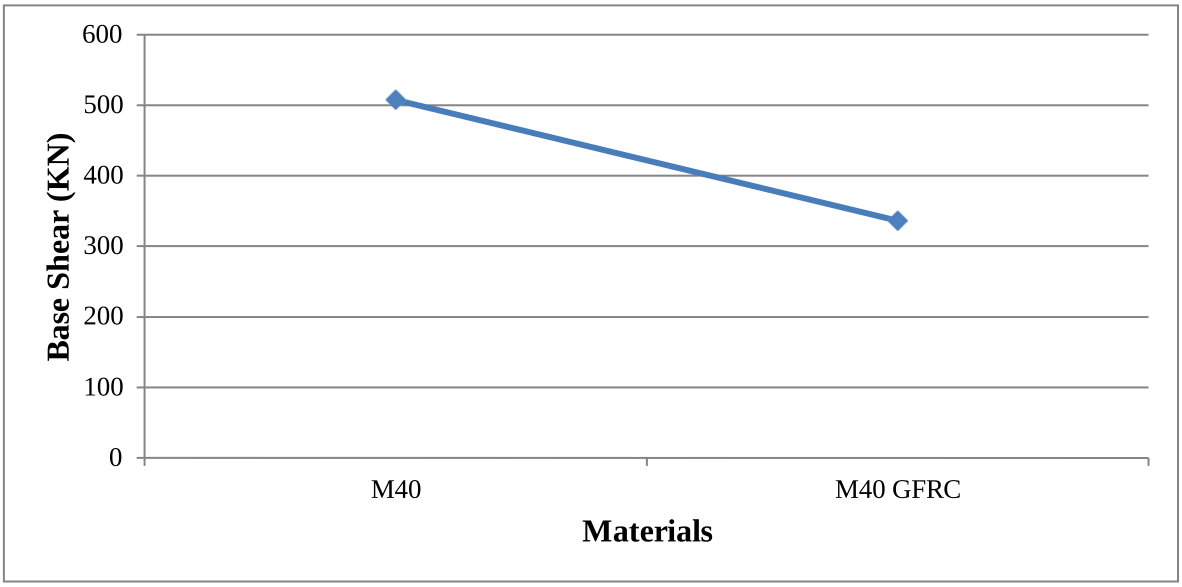


Figure 4.5 - Graph showing Base shear in X direction

The amount of maximum lateral force because of seismic ground motion at the soffit or base of the structure is base shear. It depends on following factors such as Condition of soil on the site, importance factor, Probability of significant seismic ground motion due to earthquakes, Total weight of Building, Period of the vibration. Base shear is inversely proportional to story displacement. Base of the structure is the level at which inertial forces generated in the building are considered to be transformed to the ground through the foundation. The building is constructed that it can take lateral loads due to earthquake that is equal to the base shear of the building. The seismic weight of the building is taken as the sum of the seismic weights of all the floors. Seismic weight of each floor is its full dead load plus appropriate amount of imposed load. The weights of column and wall in each storey shall be approximately apportioned to the floors above and below the storey while computing the seismic weight of each floor. Any weight supported in between storey shall be distributed to floor above and bottom in inverse proportional to its distance from the floor. Maximum shear occurs on bottom of the building. Consequently on the basis of above graph it is can be said that conventional M40 has more base shear at the bottom of silo than M40 GFRC.

Material	Base Shear (KN)
M40 GFRC	507.707
M40	336.515

Table 4.5 - showing values of Base Shear in X direction

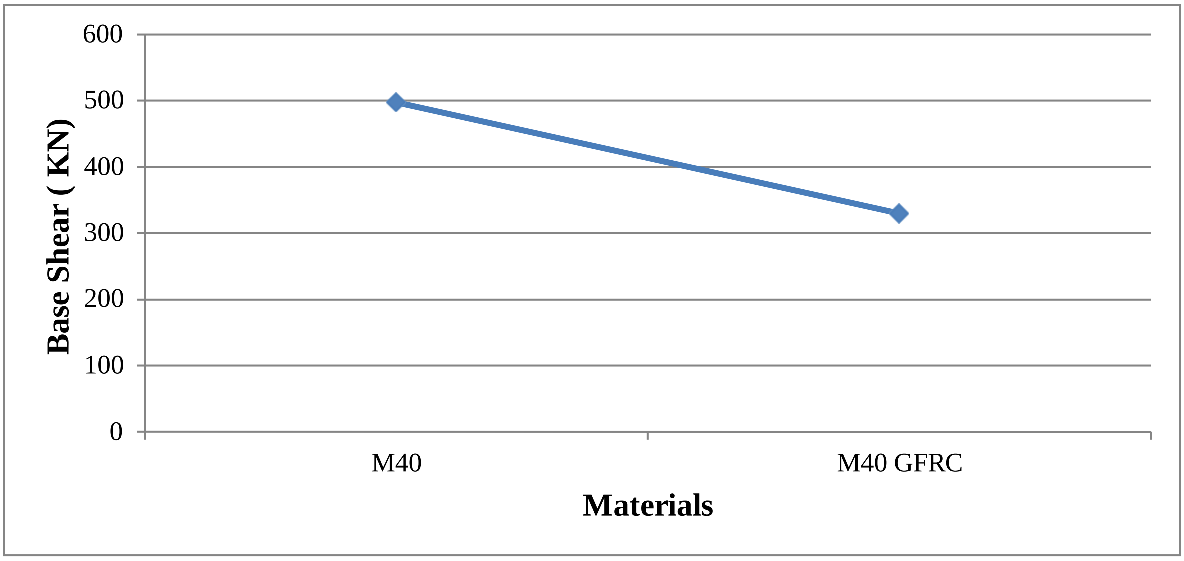


Figure 4.6 - Graph showing Base shear in Y direction

On comparison between the materials in other horizontal axis the value of base shear was computed more in conventional M40 concrete. Base shear is an estimate of maximum expected lateral force that will occur due to seismic ground motion at the base of a structure.It depends on a no of factors. Base shear correction means that in dynamic analysis, 100% mass is not contributed in each mode, that's why we multiply the correction factor with mass which you have considered for dynamic analysis. The base shear of a building with masonry will be much higher than that of building without masonry. Therefore the building having more seismic weight will be having base shear and low natural period. Similarly, zoning criteria also matters in determining base shear. The base shear of building located in zone-V will be much higher than building in zone- III. Also, design base shear is the total force that one uses to design the structural elements. Depending on which elements you are going to design the value of design base shear may be increased or decreased. It can be seen that the value of base shear is more in M40 GFRC at silo base than conventional M40.

Material	Base Shear (KN)
M40 GFRC	497.666
M40	329.9

Table 4.6 - showing values of Base Shear in Y direction

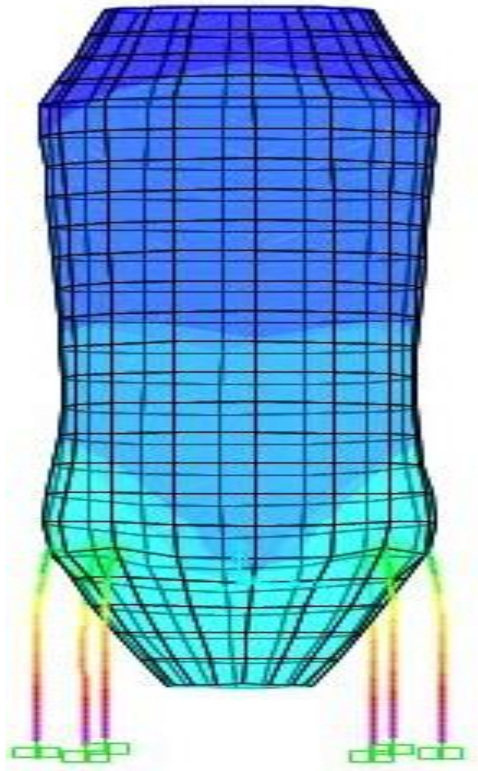


Figure 4.7 - showing deformed shape of silo under the effect of load

The terms mode shape or natural vibration shape are used in structural dynamics A mode shape describes the deformation that the component would show when vibrating at the natural frequency However, the vibration and deformation do not occur until there is an excitation Depending on this excitation, the result is the total vibration of a structural component, which is basically comprised of the individual vibration shapes. Thus, natural frequencies and mode shapes indicate how the structure behaves under a dynamic load. The amplitudes of mode shapes are not suitable for a technical quantitative evaluation of the structural component (they are properly scaled in the solution) Rather, the mode shape characteristic is suitable for the qualitative assessment of the dynamics of the structural component. The number of modes N, to be used in the analysis for earthquake shaking alonga considered direction, should be such that the sum total of modal masses of these modes considered is at least 90 percent of the total seismic mass. If modes with natural frequencies beyond 33 Hz are to be considered, the modal combination shall be carried out only for modes with natural frequency less than 33 Hz; the effect of modes with natural frequencies more than 33 Hz shall be included by the missing mass correction procedure following established principles of structural dynamics. If justified by rigorous analysis, designers may use a cut off frequency other than 33 Hz.

CHAPTER-5
CONCLUSION

5.1 Conclusion

On the basis of the results drawn from the comparative analysis of conventional concrete and glass fiber reinforced concrete, some important conclusions can be drawn which can prove helpful in establishing research. A few of the important points are mentioned below: -

1- The silo model with M40 GFRC has shown lesser displacements and story drift than the traditional M40 silo model and these values are within permissible limits i.e., not more than 0.003 times of height of structure.

2- The base shear value of conventional M40 and M30 is more as compared to M40 GFRC and M30 GFRC respectively which shows that lesser lateral force is developed at the base of the structure.

3- The shear capacity and bending moment resistance of concrete with glass fibers is better than conventional concrete. Thus, it can be said that bear the all the stresses safely.

4- With the improvement of different types of fiber reinforced polymer, they have shown better strength, durability, crack resistance, toughness and not corroded easily. So it can be provided as an admixture in the concrete for silo for have overall better seismic response.

5- On comparison of the above-mentioned parameters, it can be concluded that silo made of glass fiber reinforced concrete shows better performance than conventional concrete against seismic loads.

REFERENCES

1. Y. Di, M.W. Yuan (2001) "Ultimate load analysis of reinforced concrete silo shell roof".
2. Mohamed T. Abdel Fattah, Ian D. Moore (2005) "A numerical investigation into the behavior of ground-supported concrete silos filled with saturated solids".
3. Guang Lin Yuan, Lu Dan Tian (2011) "Analysis and Design Recommendations for the Collapse of A Concrete Silo".
4. F. Nateghi, M. Yakchalian (2011) "Seismic behavior of reinforced concrete silos considering granular material".
5. Islam M. Ezz El-Arab (2014) "Seismic Analysis of RC Silos Dynamic Discharge Phenomena".
6. Aysegul Durmus, Ramazan Livaoglu (2015) "A simplified 3 D.O.F. FEM model for seismic analysis of a silo containing elastic material".
7. Krishna Kharjule, Chittaranjan Nayak (2016) "Lateral analysis of elevated reinforced concrete silos".
8. Changdong Zhou, Lingkai Meng, Xiaoyang Zhang (2016) "Seismic Vulnerability Assessment of Reinforced Concrete Silo".
9. Alper Kanyilmaz, Carlo Andrea Castiglioni (2017) "Reducing the seismic vulnerability of existing elevated silos by means of base isolation devices".
10. Luca Pieraccini, Michele Palermo, Silvestri Stefano (2017) "On the fundamental periods of vibration of flat bottom Ground-supported circular silos containing gran- like material".
11. Christoph Butenweg, Julia Rosin, Stefan Holler (2017) "Analysis of Cylindrical granular material silos under seismic excitation".
12. Hisham Jahangir, Zahid Ahmad Siddiqi (2018) "A Simplified Approach for Analysis and Design of Reinforced Concrete Circular Silos".
13. Chrysanthos Maraveas (2020) "Concrete silos: Failures, Design Issues and Repair/strengthening methods".

14. Qikeng Xu, Hao Zhang, Lumin Wang (2020) “Seismic analysis on reinforcedconcrete group silos through shaking table tests”.

15. I.S. 875 (part 1 & part 2) - Code of practice for dead load and live load respectively for buildings and structures.

16. I.S. 1893:2016 – Criteria for earthquake resistant design of structures.

17. I.S. 4995:1974 – Criteria for design and assessment of bin loads of reinforced concrete bins for the storage of granular and powdery materials.

18. I.S. 456:2000 – Plain and Reinforced concrete- Code of practice.

19. Ansari, Armaghan and Kulkarni, S., (2016) "Design and optimization of R.C.C silo", international journal for research in applied science and engineeringtechnology, volume 4.

20. Carson, J.W. and Jenkyn, R.T. (1993) "load development and structuralconsiderations in silo design", reliable flow of particle solid 2

21. Pambher, H., Vaniya, R., (2015) "Design and analysis of circular silo (R.C.C)for storing bulk materials", international journal of advance research in engineering, science and technology volume 2

22. Tomas, j., (2013) "Silo and bunker design for reliable flow", lecture productcharacterization and processing of pharmaceutical solids.