CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Comparative Analysis and Design of Elevated Water Tank using Conventional and BIM Approach

by

Mirza Muhammad Bilal Safdar

A thesis submitted in partial fulfillment for the degree of Master of Science

in the

Faculty of Engineering
Department of Civil Engineering

2020

I want to dedicate this work to my family specially my parents, who helped me throughout my educational career. This is likewise a tribute to our best teachers who guided us to go up against the troubles of presence with ingenuity and boldness, and who made us what we are today.

CERTIFICATE OF APPROVAL

Comparative Analysis and Design of Elevated Water Tank using Conventional and BIM Approach

by

Mirza Muhammad Bilal Safdar

(MCE173005)

THESIS EXAMINING COMMITTEE

S. No.	Examiner	Name	Organization
(a)	External Examiner	Engr. Dr. Faisal Shabbir	UET, Taxila
(b)	Internal Examiner	Engr. Dr. Shuja Safdar Gardezi	CUST, Islamabad
(c)	Supervisor	Engr. Prof. Dr Majid Ali	CUST, Islamabad

Engr. Prof. Dr Majid Ali
Thesis Supervisor
June, 2020

Dr. Engr Ishtiaq Hassan
Head
Dept. of Civil Engineering
June, 2020

Dr. Engr. Imtiaz Ahmed Taj
Dean
Faculty of Engineering
June, 2020

Author's Declaration

I, **Mirza Muhammad Bilal Safdar** hereby state that my MS thesis titled "**Comparative Analysis and Design of Elevated Water Tank using Conventional and BIM Approach** " is my own work and has not been submitted previously by me for taking any degree from Capital University of Science and Technology, Islamabad or anywhere else in the country/abroad.

At any time if my statement is found to be incorrect even after my graduation, the University has the right to withdraw my MS Degree.

(Mirza Muhammad Bilal Safdar)

Registration No: MCE173005

Plagiarism Undertaking

I solemnly declare that research work presented in this thesis titled "**Comparative Analysis and Design of Elevated Water Tank using Conventional and BIM Approach** " is solely my research work with no significant contribution from any other person. Small contribution/help wherever taken has been acknowledged and that complete thesis has been written by me.

I understand the zero tolerance policy of the HEC and Capital University of Science and Technology towards plagiarism. Therefore, I as an author of the above titled thesis declare that no portion of my thesis has been plagiarized and any material used as reference is properly referred/cited.

I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after award of MS Degree, the University reserves the right to withdraw/revoke my MS degree and that HEC and the University have the right to publish my name on the HEC/University website on which names of students are placed who submitted plagiarized work.

(Mirza Muhammad Bilal Safdar)

Registration No: MCE173005

List of Publications

It is certified that following publication(s) have been made out of the research work that has been carried out for this thesis:-

Refereed conference article

1. Safdar B. and Ali M. (2019). Robot structural analysis for practicing designers in developing countries Challenges and their solution *International Civil Engineering and Architecture Conference, Trabzon, Turkey April: 17-20. Vol. 1, Page 1962-1973.*

Mirza Muhammad Bilal Safdar

(MCE173005)

Acknowledgements

- I would like to thank Almighty Allah for his countless blessing.
- I would like to pay special gratitude to **Prof. Dr. Engr. Majid Ali** for his guidance and supervision, without which, this was not possible.
- I would like to thanks all of my fellows and colleagues who supports and help me during my MS studies
- I also want to thank CUST, Islamabad for scholarship.
- I am also grateful to my family specially my uncle Nasir Ali for their continuous moral support.

Mirza Muhammad Bilal Safdar
(MCE173005)

Abstract

Elevated water tank is very important structure of the any society. It should be functional after earthquake or any kind of disaster. The water supply to the society is very essential after earthquake. However, the much important structure of the society, the research towards water tank design and analysis is very limited. The main focus of this study is on the linear design of elevated water tank. For this purpose, two softwares are used. One is conventionally used SAP 2000 and the other is auto desk robot structural analysis (ARSAP).

In past there is a lot of study done on the damages and failure of elevated water tanks in earthquake. Different types of elevated water tanks are constructed for the supply of water, which include concrete pedestals, concrete framings and mashroom type elevated water tanks. The hydraulic head of water tank that is used in this study is 60. 2B seismic zone is considered for this study. Three different types of soil profile types are considered for the design of elevated water tank i.e. SE, SD and SC. There are different codes available in market for the design of elevated water tank, but in this study UBC 97 is used for the analysis and design. Total six number of models are being analyzed Furthermore, in this study a systematical method is used to analyze the elevated water tank on SAP 2000 and ARSAP softwares.

A slight difference is observed in the results of both softwares that are used for the analysis and design of elevated water tank. The analysis on ARSAP takes less time as compared to analysis on sap2000. As structure rests on better soil, results show that the deflection is less in it as compared to the structure that is resting on soft soil. The difference in bending moment is non considerable in terms of providing of steel rebars.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background

The elevated water tanks are mostly damaged during earthquake. Because water tanks contain a huge load on their top portion and their safety performance is critical in earthquakes. They must not fail during earthquake to provide of drinking water to the society. Severely damaged water tank in past earthquake due to lack of design efficiency. Soroushnia et. al[1] reported that the dominant failure of water tank is due to earthquake forces.

The previous studies shown that there are many softwares are used for the design of elevated water tanks. Like E-tabs, SAP 2000, SAFE and Staad pro etc. many researchers worked on these softwares and compare the results of these particular designs. Eswaran et. al [2] discussed the numerical solution and compared it with different softwares and concluded that these results differ in permissible limits. Barakat et. al [3] investigated Finite element method in conjunction with optimization method is used in the analysis and design of the RC water tanks and report economical and safe design of water tank. Ferrandiz et. al [4] reported the benefits of revit architecture over the auto cad. In that study it was concluded that revit is easy and advanced tool as compared to auto cad and other softwares.

Aram et. al [5] mentioned that making use of BIM technology can improve productivity of the reinforcement in supply chain. Ren et. al [6] pointed out that the quantity of rebar resulting from the use of traditional methods is 17.76% more than that resulting from the use of BIM-based methods.

In this study, the different design aspects will be studied like the soil type will be constant for all the models and the earthquake zones will be change one by one. The structural period, deflection, moments in different elements of the water tank will be studied and compared. Ren at. al [6] studied these parameters for the high rise building by using robot Structures.

To the beat of authors knowledge on the basis of limited literature review the study on the design of water tanks by using different software has not been carried out by comparing results on SAP 2000 and Robot structures.

1.2 Research Motivation and Problem Statement

There are many softwares used in the design industry. Mostly conventional SAP2000 and STAAD PRO is used for the design of shell structures. By designing a shell structure by conventional requires a lot of efforts, time as well as expertise. These are conventional methods which are being used for the design of elevated water tower. Many issues arise while designing a structure by using these softwares. First of all, architectural drawings are made the architect by using Autocad software. The use of autocad is time consuming as well as it have many complications with the design. After that these drawings are modelled on SAP 2000 software and structure is analyzed and designed on this software. And the design process required many specialties of engineers like public health, architecture and structure etc. for operating these softwares. The purpose of this study to design all parameters under the umbrella of BIM. Therefore, problem statement is as follow.

"In any construction project there are a lot of problems that arise from its planning phase to the completion. Those problems are due to utilization of conventional

methods used for the planning, design and execution of any construction project. During the design of any shell structure mostly SAP 2000 software is used. The designers are using this software from many years. By using this software there are a lot of problems which are faced by the designers. For example, architectural drawings are being made by the architect by using AUTOCAD and then by considering these drawings structural engineer model the structure and analyze it. Many coordination issues arise during this design process. After the analysis of the structure again structural drawings are made by using AUTOCAD software. The problems of any construction project in design, execution and architecture are made by different software like auto cad SAP2000 and manual calculations. These problems can be reduced by using BIM (Rivit,Robot) analysis and design of the structure shall be compared."

1.3 Overall Objective of Research Program and Specific Aim of this MS Thesis

To reduce coordination issues in design and construction of civil structures by shifting conventional to new approach. This will be done by support from structure specialization to other specialties.

"The specific aim of this MS research work is to compare the analysis and design of elevated water tank by using SAP 2000/ SAFE / Auto cad, Revit and Autodesk robot structural analysis (ARSAP)."

1.4 Scope of Work and Study Limitation

Total six numbers of models are analyzed and designed in this study. Seismic zone for all models is fixed and that zone is 2B. Three types of soil profile types are considered for the analysis of the structure. Two models are analyzed and design on each soil profile type one in sap2000 and other on ARSAP software. SE, SD and SC are the soil profile types which are considered for the design and analysis of the elevated water tank. Comparison is made on soil profile types SC, SD and SE and two different approaches are used. Therefore, six models are considered (three conventional approach, three BIM approach).

1.5 Brief Methodology

An elevated water tank that is designed on the sap 2000 with a selected soil and seismic parameters. After designing this water tank, all the structural drawings will be produced by using auto cad. The same tank with same parameters including height, water capacity, soil and seismic parameters will be designed on a new software named ARSAP. Architectural drawings are also made on Revit architecture. After designing same water tank in new software, the compression of these two designs studied. 3 number of water tanks are designed on SAP2000 and 3 numbers of water tanks are designed on ARSAP with different properties as described earlier.

1.6 Thesis Outline

There are five chapters in this thesis, which are as follows:

Chapter 1 consists of introduction section. Damages and design techniques are explained in this chapter. It also consists of research motivation and problem statement, objective and scope of work, methodology and thesis outline.

Chapter 2 contains the literature review section. It consists of background, damages in elevated water tank, types of elevated water tanks, codes available for the design of elevated water tank, softwares for the design of elevated water tank and summary.

Chapter 3 consists of methodology. It contains background, design of elevated water tank, external stability checks, modelling, modelling in SAP 2000, modelling in ARSAP considered parameters and summary.

Chapter 4 consists of Results and analysis. It contains background, time period and base shear, external stability checks, deflected shapes bending moment diagrams, drawbacks of SAP2000 and ARSAP, variation of analysis of structural elements and summary.

Chapter 5 comprises conclusions and recommendations.

References are presented after chapter 5.

Chapter 2

Literature Review

2.1 Background

Elevated water tanks are used to store water at a particular height so that the water can be distributed under pressure to whole society. Water tank is a very important structure of any society. The importance of that structure is much more as compared to other structures. In earthquake if damage occur in elevated water tank then water supply to the society will be cutoff. These water tanks supply water to the users under hydrostatic pressure which is produced due to its elevation or head. In elevated water tanks the water supply is continued during the electricity outage. Moreover, the elevated water tanks are the life line structure for any society because water supply to the peoples are very important element to survive. Therefore, these structures must remain functional against ground motions. Failure of these kind of structure cause emergency situation in the society. In this study the main focus is on the design of elevated water tank mashroom type. This study mainly focuses on the linear design on elevated water tank. This study also focuses on different software which can be used for the design of elevated water tank. In this study, the linear and linear design of elevated water tank is carried out by the SAP 2000 as well as Auto desk robot structural analysis (ARSAP).

2.2 Damages in Elevated Water Tanks

As elevated water tanks are the lifeline structure for any housing society. These water tanks supply water to the users under hydrostatic pressure which is produced due to its elevation or head. Steinbrugge et. al [8] also studied the performance of elevated waters in earth quake occurred in the past. They concluded that the elevated water tanks performed very poorly in seismic ground motion. Ghateh et. al [9] reported in 2015 that the taller tanks had less base shear as compare to the smaller tanks. The researchers observed two cracking patterns during this investigation. First pattern was bending-shear crack pattern which travels opposite top and bottom corner of shaft. The second pattern was web-shear pattern which take place near the base and parallel to the lateral direction of the load. Steinbrugge et. al [10] reported and investigate the performance of the elevated water tower response in 1960 Chile earthquake. The researchers investigated 4000 c.m capacity elevated water tank. The studied elevated water tank was empty at the time of ground shake. The head of the said tower was 60m and the diameter of the bowl was 14.5m. In this study a very high elevated water tank is analyzed. The capacity of elevated water tank was also huge as compared to normal Elevated water tanks.

TABLE 2.1: Soil types defined in UBC97

Tank Content	**Importance Factor**
Drinking water, non-toxic non-flammable chemicals	1.25
Firefighting water, non-volatile toxic chemicals, lowly flammable petrochemicals	1.4
Volatile toxic chemicals, explosive and highly flammable liquid	1.6

Shahbazian et. al [17] investigated the damages of elevated water tank and defined the importance factors for the analysis and designed of elevated water tank as shown in Table 2.1 In that research it was reported that the importance factor for the water tank was used for the drinking purpose was 1.25. The elevated water tank that was used for the firefighting or non-volatile toxic chemicals had importance factor is 1.4. The tanks that retain volatile toxic and highly flammable liquid had the importance factor 1.6. Memari et. al [11] investigated the response of two concrete elevated water towers during the ground shake in 1990 earthquake. In this research it is reported that these tanks were designed on the design parameters at the construction time of these tanks. But the design loads of these water tanks were lesser than one fifth of the current standards.

These scholars also reported that the sloshing effect in water towers is very less or negligible. They studied some empty water towers as well in which they observed minor cracks at the base of its shaft. A new approach was used by Rai, D [12] to access the damage of existing water tank using softwares. They used static equivalent nonlinear analysis for the analysis of the elevated water tower. They estimated the damage in existing structure by nonlinear analysis of those structures. Moreover, for that study they used E tabs software. They reported the maximum displacement and damage value of the structure.

FIGURE 2.1: Damage Mashroom type Elevated water Tank [13]

Gateh et. al [13] studied an elevated water tank that was damaged shown in

Figure 2.1. This elevated water tank was about 100 km away from the origin of earthquake. He concluded that the current design practice needs to be improved for the safe design of elevated water tanks.

The soil profile types and their description defined in UBC 97 as shown in Table 2.2. SA is defined as hard rock. Soil profile type SB is defined as very dense gravels, sand or any stiff clay, at least 10m in thickness, characterized by the gradual increase of mechanical properties in depth. Soil profile type SC is defined as deep deposits of dense or medium-dense sand, stiff clay or sand with thickness 10 to many hundreds meter as shown in Table 2.2. Soil profile type SD is defined in UBC 97 as deposition of loose to medium cohesionless soil, or of predominantly soft to firm cohesive soil. Soil profile type SE is deposit of loose cohesionless soil, or of predominantly soft cohesive soil.

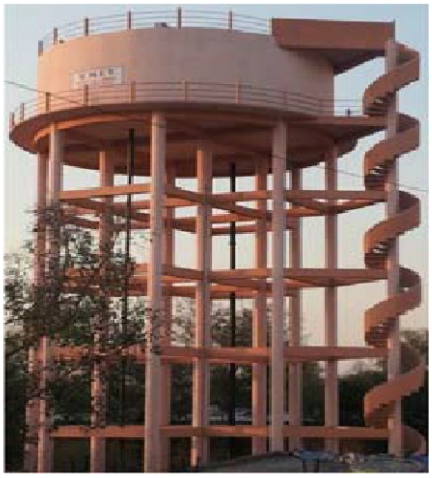
Table 2.2: Importance factors defined by [17]

Soil type	**Description of the Stratigraphic Profile**
SA	Rock or other rocks like geological formation which includes at most 5m of weaker material on the surface
SB	Deposition of very dense gravel, sand or any stiff clay, at least 10m in thickness, characterized by the gradual increase of mechanical properties in depth
SC	Deep deposits of dense or medium-dense sand, stiff clay or sand with thickness 10 to many hundreds of meters
SD	Deposit of loose to medium cohesionless soil, or of predominantly soft to firm cohesive soil.
SE	Deposit of loose cohesionless soil, or of predominantly soft cohesive soil.

2.3 Types of Elevated Water Tanks with Concentration on Mashroom Type

There are different types of elevated water tanks are used for the water supply purpose. Kianoush et. al [9] studied different types of elevated tanks and they reported that generally, four types of elevated water tanks are in practice. Steel frame, concrete frame, masonry pedestal and concrete mashroom type or concrete padestral. In steel frame elevated water tanks, the water bowl rests on the top of the steel frame. In this type of elevated water tanks, the frame of the elevated tank is made of the steel structure and the top bowl of elevated water tank was of the reinforced concrete. Masonry pedestal, in this type of elevated water tanks the pedestal of the water tank is simply made of the brick masonry. And the top bowl in which water rest is generally made of the concrete. The cost of that kind of elevated tower is comparatively less but the performance of that kind of elevated water tank is also poor specially in earth quake ground motion. Concrete pedestal, in this type of elevated water tank both pedestal of elevated water tank and its bowl are made of concrete. The performance of these kind of elevated water is better as compared to brick masonry elevated water tank. The fourth type of elevated water tank is mashroom type elevated water tank. In this type of elevated water tank, a reinforced shaft is made to attain the required head of water. The bowl which holds the water in it, rests on the slab. This type of elevated water tank has better aesthetic looks than others. This type of elevated water tank has more cost then masonry pedestal elevated tank. But study shows that this has better performance in earthquake. Steinbrugge et. al [10] studied on elevated water tanks. They evaluated the seismic performance of circular elevated water tank. This water tank has concrete frame which consist of beams and columns. On that frame a concrete circular bowl was resting. In this study mashroom type elevated water tank is used for the analysis and design. The elevated water tank has the hydraulic head of 60. The said elevated water tank model is designed on both structural analysis softwares i.e SAP2000 and ARSAP. The foundation of the elevated water is octagonal in shape. Circular shaft is designed to attain the water head for the water supply.

a)



b)

c)

FIGURE 2.2: Different type of elevated water tank dimensions a. concrete pedestal elewated water tank [9] b. Concrete framing elevated water tank [31] c. Mashroom type elevated water tank [32]

On the top of the shaft a conical bowl is made for the storage of water for supply. At the top a canopy is also provided to access on the top of the roof of elevated water tank. Railing is also provided on the top of the elevated water tank. There are different types of elevated water tanks used for the study by the different researchers. Which includes the mashoroom type, concrete pedestal and concrete framing as well shown in figure 2.1.

As shown in Figure 2.2 (a) the studied carried out by the researchers on concrete pedestal elevated water tank after the earthquake. The second type of elevated water tank is concrete framing elevated water tank as shown in Figure 3.2 (b). The third type of elevated water tank is mashroom type elevated water tank.

2.4 Codes Available for the Design of Elevated Water Tank

There are different codes that are available for the design of elevated water tank. ACI371R-08. This code was revised in 2008 in which complete design of elevated water tanks is described in detail. This code deals with the design of steel and reinforced composite elevated water tanks. In this code all parameters are described in detail which are related to the design of the elevated water tower. Another code that is available in the market is ACI 350.3R. This code is reported by the ACI committee 350. This code deals with the seismic design of liquid containing structures. This mainly deals with the seismic load on the structure, earthquake design loads, earthquake load distribution, earth quake stresses on structure, free board of the tank and dynamic model of the elevated water tank. ASCE 7-05 is also used for the design of elevated water tanks. This code is revised in 2005 and used these days for the design of elevated water tank. ACI 318-08 is being used for the design of elevated water tower. This code deals with the design of elevated concrete water tanks. UBC 97 is also used by the designers to design of water tanks. This code was generated in 1997 and it has a portion which deals with the design of water tanks. BCP 2007 code is widely used in Pakistan for the design of elevated water towers.

2.5 Softwares for the Design of Elevated Water Tank

Different softwares are used for the design of elevated water tanks. In past,scholars used different softwares for the design of elevated water tanks. Generally, STAAD PRO and SAP 2000 is mostly used for the design of shell structures. Lallotra et. al [15] studied the competitive design of elevated water tank by using SAP2000 and STAAD PRO software. They concluded that the results of STAAD PRO are much accurate than SAP2000. But SAP2000 provides much flexibility in modelling. . Moulik Tiwari et. al [16] investigated the seismic behavior of elevated water tank with different staging patterns. They used SAP2000 software for that evaluation. E-tabs can also be used for the design of elevated tank. But the limitation of this software is that E-tabs is unable to design shell structure. Frame structure elevated water tanks can be designed and analyzed using E-tab. ARSAP is a new emerging software in the market. This can also be used for the design of elevated water tank.

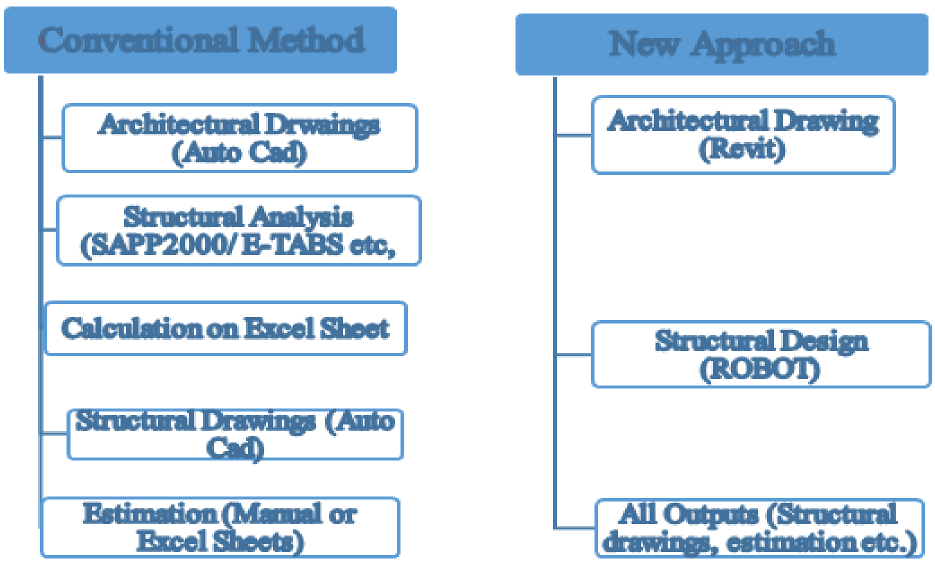


FIGURE 2.3: Comparisons between new and conventional approach

Two type of the approaches are discussed as shown in Figure 2.3. One is conventional approach and other is new approach. In conventional approach it takes a lot of time for the complete analysis and design of elevated water tank. In this approach architectural drawings are made by using autocad software and then these drawings reach to structural engineer and structural engineer model these drawings in SAP2000 and other software. After analysis which also include manual calculations, structural drawings are made using AUTO CAD. But in new approach the input or architectural drawing are made by using revit software and then the same model is designed on ARSAP and then analysis carried out and output drawings are again made using revit software.

2.5.1 SAP 2000

SAP software 2000 is widely used for the design of elevated water tower. Many researchers and designers are using this software for the analysis and design of different structures as well as elevated water tanks. Pezeshk [17] the researchers used sap 2000 software for the analysis of elevated water tank. In that research, time history analysis in frequency domain is done by spectral matching procedure. Soroushnia et. al [18] also investigated the nonlinear design of elevated water tower. Seismic performance of RC elevated water tanks with different staging patterns are investigated in that research. SAP 2000 software was used for that study. Yang et. al [19] the investigation of elevated towers that are used for the storage of water by using SAP 2000 software. Non linear analysis was carried out for this study. Time domain spectral matching of earthquake ground motions analysis was done for that study. Patel et. al [33] investigated the elevated water tank is done by using SAP 2000 software. In this study, the optimum diameter of the staging with reference of the diameter of bowl of water tank and observed the diameter of the staging batter. Lakhade et. al [31] also conducted the analysis of elevated water tank and access the drift limits for the for the earthquake damages of Reinforced frame staging elevated water tanks. In that study, the top drift of the elevated water tower is noted and at that particular drift damage is obtained in that structure. Ferrandiz et. al [4] investigated the design of elevated water tower by modelling in SAP 2000 software. In that study, two case of elevated water tank were studied one was empty and other was full. Time history analysis of the structure was carried out by using different earthquake acceleration record.

2.5.2 ARSAP

In new times, for the design of elevated water tank or other civil engineering structures ARSAP is used. The world is moving from conventional to new method or softwares for the design and analysis of structures. Beg et. al [34] studied about the new software that are being used now a days and discussed its benefits. In conventional method, steel connections are still manually designed. But in new technique, ARSAP is used for the analysis and design of structure in which these connections are designed automatically by the software. Nguyen et. al [35] studied about the ARSAP software and compared it with conventional methods that are used for the design and analysis of structure. In this study it is concluded that the ARSAP saves the time as compared to other softwares.

2.6 Summary

Water supply has been one of the basic needs of human being from the beginning of life on earth. For that purpose, different types of elevated, ground and underground water tanks are constructed. Due to supply under head, elevated waters are mostly constructed in housing societies. With the passage of time world is progressing towards the safe and economical design and construction of elevated water tanks. As study shows that most of the elevated water tanks are damaged in earthquake. There are different codes available for the design of elevated water tanks. In past, mostly STAAD PRO and SAP2000 softwares are commonly used for design of elevated water tank. In this study ARSAP software is used and its results are compared with SAP2000.

Chapter 3

Experimental Program

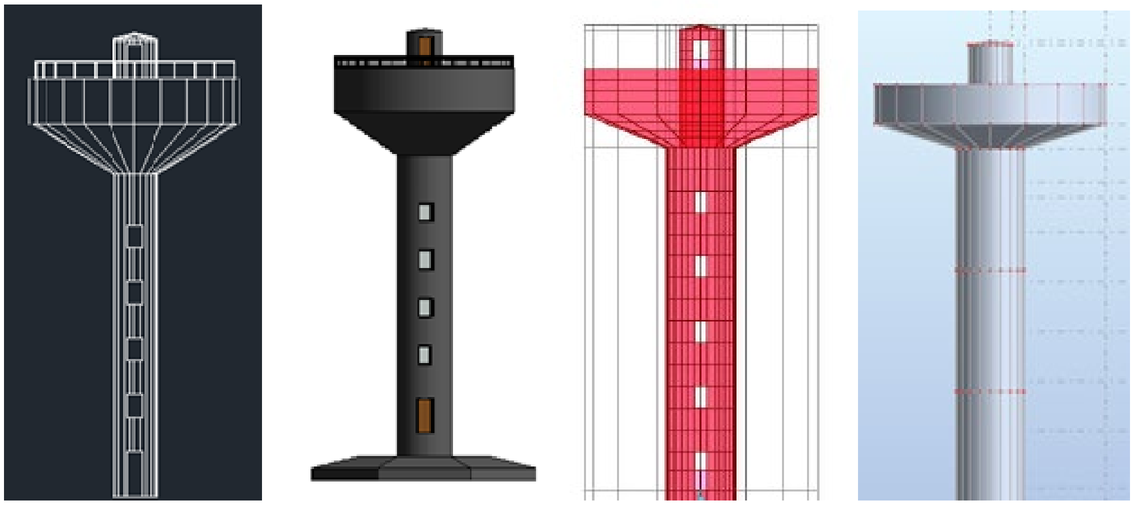
3.1 Background

Elevated water tanks are one of the important structures of any society. In these water tanks water flows under the gravity and no power is required for the supply of water to the consumer. Different softwares are used for the design of elevated water tanks. Commonly the structural design of elevated water tanks is carried out by using SAP2000 which is a conventional technique. In this technique the architectural design of elevated waters tank is carried out by using Autodesk Auto cad software. Which is a typical way to make architectural drawings. After the completion of architectural drawings these drawings are handed over to the structural engineer. Structural engineer model the structure on SAP2000 or any other software for the structural design of elevated water tank. After modelling and analysis, the structural drawings are again made by the draftsman by using autocad software. But now a days, new techniques are being used for the design of elevated water tanks or other structures. Another way to design the elevated water tanks is to make all the architectural drawings are made by revit architecture software which is very easy and have better understating comparatively. In this software, the drawings are made easily and less time as compared to older softwares. Moreover, these drawings have better understanding during the construction of elevated water tanks. The sections and member details are very clear and easily understandable for the site engineer as well as for the better understanding of the structural engineer. After the completion of these architectural drawings, these drawings are handed over to the structural engineer and he model the drawings in a software named ARSAP for the structural design. This model is analyzed by using ARSAP that produces the structural drawings by using revit architecture. Autodesk robot structural analysis for professionals (ARSAP) is a new software that is used for the design of different kind of structure. Safdar and Ali (2019) studied about the issues that are being faced by structural engineers in usage of ARSAP. They conduct a survey from structural engineers that are working in different organizations and proposed its solution as well.

3.2 Description of Elevated Water Tank

Design of elevated water tanks is done by different softwares. Two types of designs are done during the design of elevated water tanks. First is architectural design and other is structural design. Architectural design contains the details about the architectural or aesthetic feature of any structure or elevated water tanks. While structural drawings contain the structural details of the elevated water tank. In this type of drawing, the steel details, member size and their required strengths are described. Architectural drawings are made by using autodesk auto cad conventionally the outlook in this software look like Figure 3.1(a). In this software the structure is architecturally model by using line command. In this software mostly 2D or 3D models are designed architecturally. By using this software, it takes a lot of time to design an elevated water tank. It also requires expertise as well as special attention for the design.

REVIT architecture has some different features from the Autodesk AUTOCAD. In this software architectural drawings have better understanding and it takes less time to design an elevated water tank with better understanding. In this software



a) b) c) d)

FIGURE 3.1: Elevated water tanks in Different Softwares. a. Architectural Model by using Autocad. b. Architectural Model by using Revitd. c. Structural Model by using SAP2000. d. Structural Model by using ARSAP.

chance of error is minimum as compared to autocad. The member thicknesses are defined in the properties so that it is quite easy to design structure or elevated water tank. It has better appearances of the structure that is modelled in software. As shown in Figure 3.1 (b) It is clearly visible that differences between design of elevated water tank in AUTOCAD and REVIT. In this software you can place windows and doors which gives a real look after construction. Some common and standardized sizes and design of these features are given in the library of this software. But if you want to get a design or size of a door, window or any other member you can easily define that element and place it on desired place.

For the structural design of elevated water tank there are different softwares available in market which are used for the structural design of elevated water tank. Commonly, SAP2000 is used by the designers for the structural design of elevated water tanks. In Figure 3.1 (c) the SAP2000 model is shown. This is conventional technique which is used by the designers for the analysis and design of elevated water tank. In this software model takes a lot of time for its creation. It needs special attention while defining the geometry as well as member sizes, thicknesses and their other properties. More chances of errors are in this software. Moreover, there are many coordination issues are also there in conventional technique. In this technique the analysis is carried out by using SAP2000 and structural drawings are made by using autocad software. Which takes a lot of time and needs different

TABLE 3.1: Description of water tank used in this study

Aspect	**Description**
Tank type	Elevated (Mashroom type)
Capacity	50000 gallons
Minimum hydraulic head	60'
Shaft dia	12'
Shaft thickness	12"
Bowl base slab thickness	36"
Bowl inclined wall thickness	18"
Bowl external wall thickness	12"
Bowl internal wall thickness	12"
Bowl top slab	9"
Canopy shaft	6"
Raft size (octagonal, width for SE soil type)	52'
Raft size (octagonal, width for SD soil type)	43'
Raft size (octagonal, width for SC soil type)	34'

expertise for the complete structural design of elevated water tank. But now a days some designers are using new software which is named as ARSAP. In this structural engineering technique, mostly architectural drawings are made by using revit architecture which have better understanding and describe its all features much better as compared with AUTOCAD, which reduces the coordination issues as well as understanding issues in design phase. After that design, elevated water tank is modeled on ARSAP. Model of ARSAP is show in Figure 3.1 (d). In this software, after modeling analysis is carried out and the structural drawings are made by using revit software. A shell made up of a single isotropic material with a ratio greater than 1/15 is considered as thick if the ratio is less than 1/15, the shell is considered as thin. In this study, thin sections are used. These estimates are approximate, designers should always check the transverse shear effects in their model to verify the assumed shell behavior.

All parameters that are used in this study are shown in the Table 3.1. These parameters are same in all models so that comparison can be made on different software. The type of elevated water tank used in this study is mashroom type in all models. The minimum water head kept 60 in all models so that water can supply under gravity at desired height. The diameter of vertical shaft is kept 12 in all models and the thickness of this shaft is 1 foot in all models that are designed in different softwares. The thickness of the base slab is 36 because it has to bear sudden chunk of load on it. And the thinness of inclined slab of the bowl was 18 to 15 in all models to control the stresses. Its maximum thickness is 18 and reduces at it travel outward up to 15. The thickness of the outer wall of the elevated water tank is 12 to control the stresses. The internal wall of bowl also has thickness of 12. The thickness of the upper slab of the elevated water tank is 9 in all models to bear the stresses produced in it. A canopy is also on the top of the elevated water tank. The thickness of the shaft of the canopy is 6. These all water tanks have the raft foundation of the octagonal shape. While designing an elevated water tank soil profile type SE and seismic zone 2B the width of octagonal shape is 52 and 5.5 in depth. This size of raft is same in both softwares analysis i.e. SAP2000 and ARSAP as well. In the design of elevated water tank that rests on seismic zone 2B and soil profile type SD. Same shape of raft foundation is provided and its width is 43 and depth is 5 in both models SAP2000 as well as ARSAP. In the design of elevated water tank that exist in seismic zone 2B and soil profile type SC the same shape of the foundation is used. The width of that octagonal raft is 34 ad its depth is 4.5. The trend of the foundation shows that as soil type changes towards good soil the size of foundation reduces accordingly. The depth of foundation also reduces as soil profile type changes towards SE to SD and after that SC. The shape of the foundation remains constant is all models either designed and modeled in SAP2000 and ARSAP. Octagonal shape of the foundation is selected for that design.

3.3 Modelling

In conventional approach first modelling is done by using SAP 2000 software and in new approach modelling is done by using ARSAP for the structural analysis of the elevated water tank.

Table 3.2: Number of models

	Zone 2B	
Soil profile type	**SAP/SAFE**	**ARSAP**
SE	1	1
SD	1	1
SC	1	1

Total six numbers are modelled and analyzed in this research as shown in Table 3.2. Seismic zone for all the models are same which is 2B but soil profile types are change accordingly. Two number of models are designed on the soil profile type SE. In which one model is analyzed in SAP/SAFE softwares and the other is analyzed and design in ARSAP. The properties of both models are constant so that the result can be compare. The next two models are on soil profile type SD. This one is modelled in ARSAP software and other is in SAP 2000. The last two models are designed and analyzed on soil profile type SC as shown in Table 3.2. In these two models one is analyzed on software SAP 2000 and the analysis of the other is carried out by using ARSAP software. All the parameters in these two softwares are same so that comparison can be done with in the results of both models. In ARSAP, only elevated water tank is modelled and analysed. No any simplified model is analysed in this study.

Some parameters are constant in the study for the analysis and design of elevated water tank. As shown in Table 3.3 the compressive strength of concrete is used 3000 psi and 4000 psi. Yield strength that is used in this study, is 60,000 psi. Seismic zone is also constant 2B for all the models and allowable bearing capacity of the soil is considered as 1.9 TSF.

TABLE 3.3: Constant input parameters

Parameters	**Values**
f'_c (raft and shaft)	3000 psi
f'_c (bowl)	4000 psi
f_y	60,000 psi
Seismic zone	2B
q_e	1.90 TSF

TABLE 3.4: Input Parameters for Static Analysis

Member	**Modifier**
Shaft Wall	0.70
Base slab of bowl	0.35
Bowl inner wall	0.70
Bowl base slab	0.35
Bowl outer wall	0.70
Bowl top slab	0.35
Dome of canopy	0.5

There are some modifiers used for different elements as shown in Table 3.4. The modifiers for the shaft, bowl inner wall and bowl outer wall are considered 0.70. The modifiers for bowl base slab and bowl top slab is considered as 0.35 and for the shaft it is considered 0.70 These modifiers are used by following UBC 97 code section 1633.2.4".

The load cases shown in table 3.5 are used for the design of elevated water tank. And default load combinations are used for the analysis procedure. In both softwares the same load cases are used. Self load of the structure is considered in both softwares. Super imposed live and roof live load is also considered for the analysis and design. Earth quake load in both x and y direction is considered in + and values. Most importantly water load is considered for the analysis and design of elevated water tank.

TABLE 3.5: Load cases

Load Case	**Load Case Type**
Self	Linear static
Superimposed	Linear static
Live	Linear static
Live roof	Linear static
Ex	Linear static
Ey	Linear static
Ex'	Linear static
Ey'	Linear static
water	Linear static

3.3.1 In SAP2000 and SAFE

First of all, architectural drawings are made by using AUTOCAD and then these drawings reach to the structural engineer. Structural engineer model the structure on SAP2000. By considering these architectural designs structural engineer model the structure in SAP2000 for the analysis and design of structure. The modelling in SAP2000 takes a lot of time and needs expertise.

While modeling the structure in SAP2000 the elevated water tank will look like as shown in Figure 3.1(c). The places where openings are required these elements are deleted from that places. In modelling phase different kind of modifiers, their strengths and sizes are described and used where desired. All modifiers and strengths that are used for the design of elevated water tanks are described in Table 3.4. The modifier for the shaft wall is 0.7 and the compressive concrete strength in this shaft is considered 3000 psi. The modifier for the bowl slab is considered 0.35 and the compressive strength of concrete for that particular member is used 4000 psi. Another vertical member of the elevated water tank, inner wall of water tank, the modifier used for that member is also 0.70 and its compressive strength is considered 4000 psi. The considered parameters for the bowl base slab is 0.35 factor as per the modifier and the compressive concrete strength for that member is same as its adjoining members 4000 psi, while modelling the bowl outer wall. All of its parameters are considered and described at that time. The crack modifier for that member is 0.70 and the strength of concrete is also considered 4000 psi. Although the stresses and load on the domb of canopy is very less the compressive strength of that concrete is also considered as 4000 psi because similarity of adjoining members. The crack modifier for the domb slab is also 0.35. After the modelling all these elements and defining their properties, meshing is done for all elements. As shown below in Figure 3.2. Different size of meshing is done for different members. The important element that was considered during meshing is that the edges of all elements coherent with each other. Different sizes of meshing are selected for different members. The purpose of meshing is to break an element into small pieces. Each meshed element behaves like a single member.

The accuracy of the analysis depends upon the meshing. So, it is very important, during meshing that structural element their angle concede with each other.

3.3.2 ARSAP Model

While the structural design is carried out by using ARSAP the model will look as shown in Figure 3.1(d). The architectural design is carried out by using REVIT ARCHITECTURE. After completion of architectural design, the modelling procedure starts in ARSAP software by structural engineer. The modelling in ARSAP takes a lot of time and needs special expertise. In designing phase different parameters are considered carefully. Different crack factors are considered while defining the element properties as shown in Table 3.4. All factors remain same in both while modelling in both softwares i.e. SAP2000 and ARSAP. While defining the elements properties the strength of concrete is also defined in properties for the elements. Two types of strengths are used for that design 3000 psi and 4000 psi. The strength parameters are same in both softwares so that comparison can be made. After defining all these parameters meshing is done before the analysis of the elevated water tank. The meshing parameters are also same in both softwares. It is considered while meshing is done that all joints and nodes of the meshed elements concedes each other.

Meshing size in shaft is considered 1x2 feet in both softwares as shown in Figure 3.2. For shaft the size of meshed element is same in both softwares so that comparison can be made and to ensure the quality and checks on the design. The meshing size of inclined bowl is 2x2 feet as shown in Figure 3.2(b). This size of meshing is selected considering in mind that each node of that element concedes with the elements of shaft as well as the vertical wall of the bowl. Meshing of the elements is compulsory to ensure the precision of the analysis. Each single meshed element behaves like an independent member. The meshed size of the vertical wall of the bowl as shown in Figure 3.2 (b) is 4x2 feet. The size of meshed elements selected while considering the size of the meshed adjoining elements. The geometry of elements is not similar. So, for the uniform distribution of load and for node to

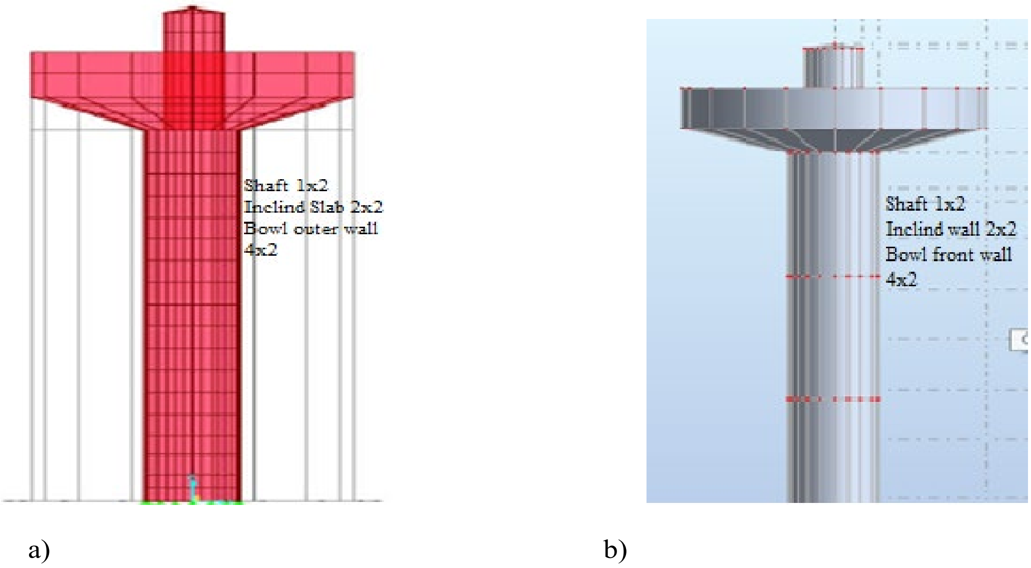


FIGURE 3.2: Meshing in different softwares a. In Sap 2000 b. In ARSAP

node connections, different mesh sizes are used. Moreover, this approach has node to node connection therefore take less computational time.

3.4 Considered Analysis and Design Parameters

The time period and base shear of the elevated water tank is considered for the analysis of elevated water tank. The seismic analysis and design of elevated water tank is based on the time period of the structure and base shear. These two parameters are considerably different while soil profile type changes. External stability checks are also important parameter for the analysis of structure. Over turning, stability and bearing pressure of the soil is considered for the surety of the stability of structure. Maximum deflection of the water tank is also considered while analyzing the structure. Maximum deflection against the envelope is considered. The bending moment is also very important parameter of the analysis and design of the elevated water tank. The steel rebars are provided against the maximum and governing bending moments in all members of the structure.

3.5 Summary

Methodology is the important chapter of this study. In this chapter, the methodology of the design of elevated water tank in both softwares are described well. All the sizes for the elements of elevated water tanks are decided and kept same in both softwares for the comparison of the design. All crack factors are described in detail. Meshing is also an important parameter for the correct result of the design. After meshing, single meshed element behaves like a single member. But the meshing size is same for the both softwares so that comparison can be made. The earth quake factor that is considered for the design and is 2B for that elevated water tank. And three different types of soil profile type is considered for that study.

Chapter 4

Results and Analysis

4.1 Background

Analysis of the elevated water tank is done by using both softwares i.e. SAP2000 and ARSAP. All Bending moments and stresses are observed carefully and compared with each other. After comparing these design parameters in both softwares the structural steel as well as member sizes are decided. Deflected shapes are also observed in this study as well.

4.2 Time Period and Base Shear

Time period of the elevated water tank on different soil profile type is studied in this study. This study is carried out in both structural analysis softwares i.e. SAP2000 and ARSAP. As shown in Table 4.1. Base shear is the first parameter that is studied in this research. Different base shear is observed in different software as well as soil profile type, while seismic zone remains constant. For seismic zone is 2B and soil profile SE the observed base shear is 1495 and 1489 kips in both structural analysis softwares SAP2000 and ARSAP respectively. When soil profile type changes into SD the noted values of base shear are 1506 and 1501 kips in SAP2000 and ARSAP, respectively. In third group, the soil profile type considered as SC and the values of base shear is 1513 and 1509 kips in SAP2000 and ARSAP, respectively. When soil profile type changes into SD the noted values of weight are 1503 and 1501 kips in SAP2000 and ARSAP, respectively. In third group, the soil profile type considered as SC and the values of weight of structure is 1503 and 1501 kips in SAP2000 and ARSAP, respectively. Another parameter that is noted in this study is time period. Time period is noted in both direction x as well as y direction. In x direction while the soil profile type is SE the time period is 1.11 sec in SAP2000 and 1.05 sec in ARSAP. When soil profile type considered as SD the time period noted as 1.10 sec and 1.05 sec in SAP2000 and ARSAP respectively. For soil profile type SC, 1.05 sec and 1.04 sec is noted in both softwares SAP2000 and ARSAP, respectively. The trend shows that as soil profile type moves towards good soil or SE to SD and then SC the time period reduces in term of time as shown in Table 4.1

TABLE 4.1: Seismic Analysis Parameters

Parameters	Zone 2B					
	SC		SD		SE	
	SAP	ARSAP	SAP	ARSAP	SAP	ARSAP
W (kips)	1503	1501	1503	1501	1503	1501
Tx (sec)	1.05	1.04	1.10	1.05	1.11	1.05
Ty (sec)	1.08	1.05	1.12	1.09	1.2	1.15
Vx (kips)	233	224	358	349	487	477
Vy (kips)	249	238	352	343	454	442
Ftx (kips)	19.25	18.75	28.5	27.90	38.00	37.50
Fty (kips)	19.25	18.75	28.5	27.90	38.00	37.50

Time period in vertical direction or y direction is also noted which is also shown in Table above. While soil profile type is considered as SE, the noted time period is 1.2 sec in SAP2000 software and 1.15 sec in ARSAP software. Then soil profile type changes in to SD, the time period in y direction is noted 1.12 sec in SAP2000 and 1.09 in ARSAP. In soil profile type SC, the time period noted in SAP2000 software is 1.08 sec and 1.05 sec in ARSAP. These all time periods are noted and and calculated under the envelope of load cases in both softwares i.e. ARSAP and SAP2000.

Force in x direction and y direction is also calculated by both softwares and against three types of soil profile types. Soil profile type SE and zone 2B, in this zone and soil profiletype the base shear is noted 487 kips in SAP2000 and 477 kips in ARSAP software is noted in x direction of the structure. While the soil profile changes into SD and the zone is same as previous. The base shear noted in the direction of x is 358 kips in SAP2000 and 349 kips in ARSAP. This trend shows that the force reduces as soil profile type changes from SE to SD. In structures that lies in seismic zone 2B and soil profile type SC the force in x direction is noted 233 and 224 kips in SAP2000 and ARSAP respectively. This fashion also shows the same trend as previous trend is noted. The same type of forces are noted in y direction. The forces in y direction while soil profile type is SE and seismic zone is 2B the value is noted 454 and 442 kips in SAP2000 and ARSAP, respectively. In soil profile type is SD and seismic zone is same as previous the values are 352 and 343 in SAP2000 and ARSAP, respectively. In y direction, when soil profile type is SC and seismic zone is 2B 249 kips is noted in SAP2000 and 238 kips is in ARSAP software. Another parameter that is studied in this research is force that is acting on the top of the structure in both softwares i.e. SAP2000 and ARSAP. The force acting in x direction on the top of the structure, which lies in 2B zone and SE soil profile type is 38 kips in SAP2000 software and 37.5 kips in ARSAP. While analyzing that structure that is laid in soil profile type SD and seismic zone 2B the force acting in x direction is noted as 28.5 and 27.90 in SAP2000 and ARSAP, respectively. When analyzing the structure that lies on SC soil profile type, force on top in x direction is noted as 19.25 and 18.75 kips in SAP2000 and ARSAP respectively. The trend of these results show that as structure is resting on good soil type its force on top is reducing accordingly. Similarly, the forces are observed in y direction the force on top is noted 38 kips in SAP2000 and 37.5 kips in ARSAP software. Soil profile type SD in SAP2000, 28.5 kips is noted and in ARSAP the force in y direction is observed in 27.90 kips. Soil profile type SC the results in y direction, in SAP2000 is 19.25 kips and in ARSAP 18.75 kips is noted.

4.3 External Stability Checks

External stability checks are applied to the structure of the elevated water tank. After the clearance of these checks, the structural stability is verified and then the member sizes are finalized as well. Three types of the external stability checks are applied on each model of the elevated water tank.

TABLE 4.2: External stability checks

		Zone 2B		
Calculation Approach	Checks	SC	SD	SE
Manual	Overturning	2.27>2	2.42>2	2.67>2
Manual	Stability	2.8> 1.5	2.8> 1.5	2.82> 1.5
Manual	Bearing pressure	1.79< qe	1.74< qe	1.89< qe
Safe	Bearing pressure	1.75< qe	1.70< qe	1.84< qe
ARSAP	Bearing pressure	1.77< qe	1.74< qe	1.87< qe

These are all external stability checks that are applied to all models. These checks include over turning, stability and bearing pressure check. These all checks are applied to all three type of models. First of all, first check is applied on the elevated water tank that is overturning check for the elevated water tank model that exists on the soil profile type SC, the overturning factor came 2.27 which is lesser than 2. 2 is the factor of safety that is defined by the code and the value 2.27 is quite safe as compared with 2. Soil profile type SD, the overturning check is applied on the elevated water tank and the value came is 2.42 which is reasonable more than the factor of safety that is 2 as described by the code. The elevated water tank that exists on soil profile type SE, the same check is applied on the structure and the result came 2.67 which is much more than 2 and hence it shows that the structure is quite safe against this check.

Another external stability check that is applied on the elevated water tank is stability check. While elevated water tank that exists on soil profile type SC, the value came 2.80 and the factor of safety that is defined by the code is 1.5. The value 2.8 is reasonably higher than 1.5 which indicates that structure is well safe in this respect. The elevated water tank that rests on the soil profile type SD, the factor of stability came 2.8, which is much higher than the 1.5 and structure is safe enough in this respect. The elevated water tank that exists on soil profile type SE and seismic zone 2B, the value of that check came 2.82 which is quite higher than 1.5 and elevated water tank is well safe against this check. Third and last external stability check is applied on the structure which is bearing pressures check. The elevated water tank that rests on the soil profile type SC and seismic zone 2B the bearing pressure on the soil value is 1.79 which is lesser than qe that indicates the structure is safe. Another structure in which elevated water tank exists on soil profile type SD and in same seismic zone 2B 1.74 the value is quite lesser than qe which indicates that structure is safe. On soil profile type SE the value of bearing capacity came 1.89 which is much higher than the qe and structure is safe in this respect. The trend shows that as the size or area of the foundation increases this check became much safer. The bearing capacity of the elevated water tank is also confirmed from the softwares as well as shown in Table 4.1. The results from the software shows that these all checks are clear and no issue exists. The results for structure rest is on SC soil profile type, the value came 1.75 which is quite lesser than the qe safe. While the same structure that is analyzed in ARSAP the result came 1.77 which is also safe bearing pressure. The model that is resting on soil profile type SD the results that obtained from safe is 1.70 and the results obtained from the ARSAP is 1.74, both results are in safer zone. The structure that rests on soil profile type SE analyzed by the both softwares i.e. safe and ARSAP results came 1.84 and 1.87 which are laying in safer zone as well. In Figure 4.1 the bearing pressure noted in safe software and ARSAP on soil profile type SE and seismic zone 2B are shown.

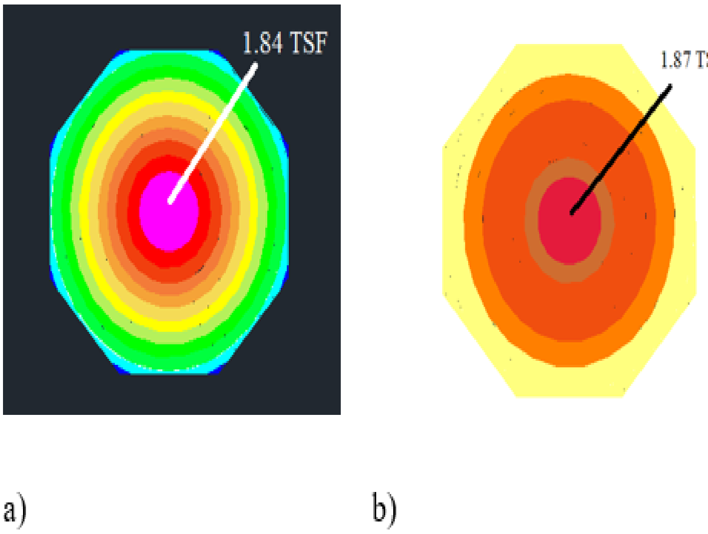


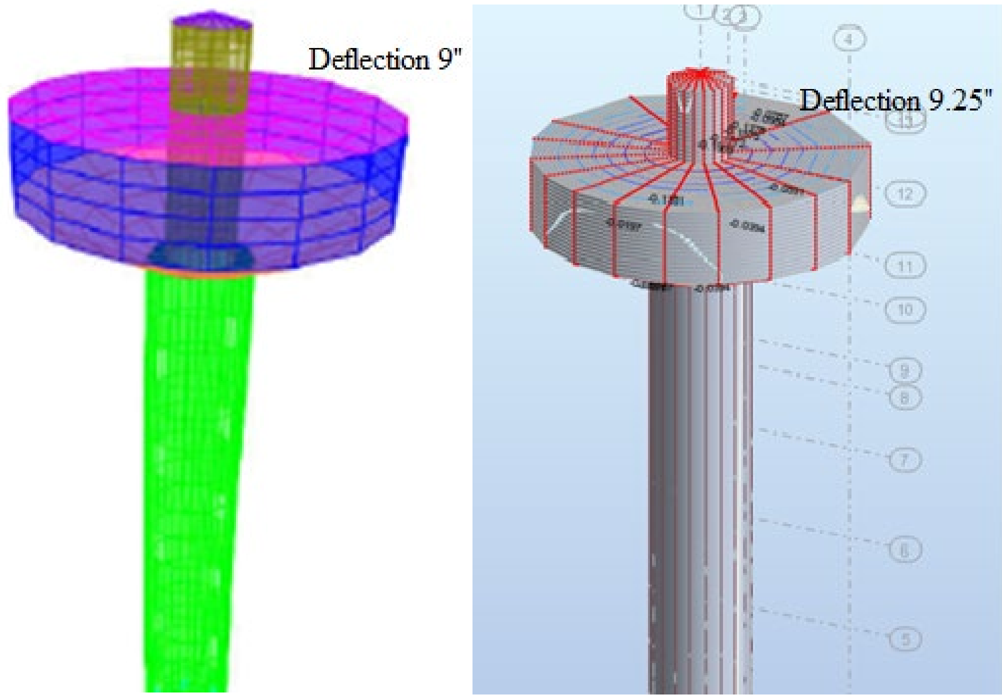
FIGURE 4.1: Bearing pressure a. In SAFE b. In ARSAP (Zone 2B, Soil profile type SE)

4.4 Analysis of Elevated Water Tank

4.4.1 Deflected Shapes

After the analysis the deflected shapes can be observed in all analysis softwares. The deflected shapes can be optional in any kind of loading as well as load cases. The deflected shapes in both structural analysis softwares i.e. SAP2000 and ARSAP are shown in Figure 4.2 (a) and (b). The deflected shape of the SAP 2000 software shown in Figure 4.2. The deflected shape against envelope is shown in Figure 4.2(a) this shows the deflected shape after analysis is done. The deflection in x direction is about 8 while structure is being analyzed in SE soil profile type and seismic zone in 2B. At that similar time deflection in y direction is observed 9 and 9.25 downwards in z direction. The similar trend of deflected shapes is also observed in ARSAP software.

The values of deflected shapes are same as in SAP2000 because the same load cases and combinations are used in both softwares i.e. SAP2000 and ARSAP. The software also gives the option to check the deflected shape against different load cases and combinations. The deflected shapes that are shown in figure 4.2 (a) and (b) are against envelope. It shows the maximum deflection which can be produced in structure as shown in these figures. The deflected shape shows in Figure 4.2 (b) shown the deflection that is observed in the ARSAP. The deflection trend in ARSAP is same as in SAP2000. In ARSAP also deflection shapes can be visible against any load case or combination as well.



a) b)

FIGURE 4.2: Deflected Shapes in Different softwares. a. In Sap 2000 b. In ARSAP when using soil profile type SE

TABLE 4.3: Maximum deflection on different soil profile type

Soil profile type	Maxium Deflection (inches)	
	SAP2000	ARSAP
SC	6.0	6.2
SD	7.0	7.25
SE	9.0	9.25

The maximum deflection is observed on different soil profile type as shown in Table 4.3. The maximum deflection in a structure that lies on soil profile type SC is noted 6.08 in sap2000 and 6.20 in ARSAP. The maximum deflection of water tanks that rests on soil profile type SD is 7.16 in sap and 7.25 in ARSAP.

4.4.2 Bending Moment

Bending moment is the important parameter in analysis. Because providing of reinforcement depends on bending moment produced in any element of the structure. Different members have different bending moments according to their sizes as well as forces applied on it. It is observed in this study that trend of bending moment is same in both softwares i.e. ARSAP and SAP2000 but the values differ a bit because of the softwares. In all models it is observed that the result trends are quite similar to each other in both softwares. The reinforcement is provided to resist that bending moment. Basically, bending moment is the reaction produced in any structural element because of an external force or external moment applied on the member and that force or moment cause the bending in that element. The bending moment observed in different important element of the elevated water tank is shown in Figure 4.3. As shown above the bending moment in raft is observed in both softwares. The governing moment as shown in raft in SAFE is 1250 kip-ft. The maximum moment is observed at the bottom of the shaft. This governing moment as shown in figure above is against the soil profile type SE and seismic zone is 2B. The governing moment as seen in ARSAP analysis in the raft octagonal in shape is 1200 kip-ft. The maximum or governing moment is also at the same position as in SAP2000. But the thing needs to be noted the trend and the shape of the contours are same in both softwares results. At the bottom of the shaft the governing bending moment in that portion is noted 20 kip-ft. The critical portion in the lower portion of the shaft is at the bottom of the shaft.

In ARSAP, in lower portion of the shaft the governing or maximum value of the moment is 19.5 kip-ft. The governing moment governs at quite similar point in SAP2000 portion. The maximum moment is observed at the bottom of the shaft.

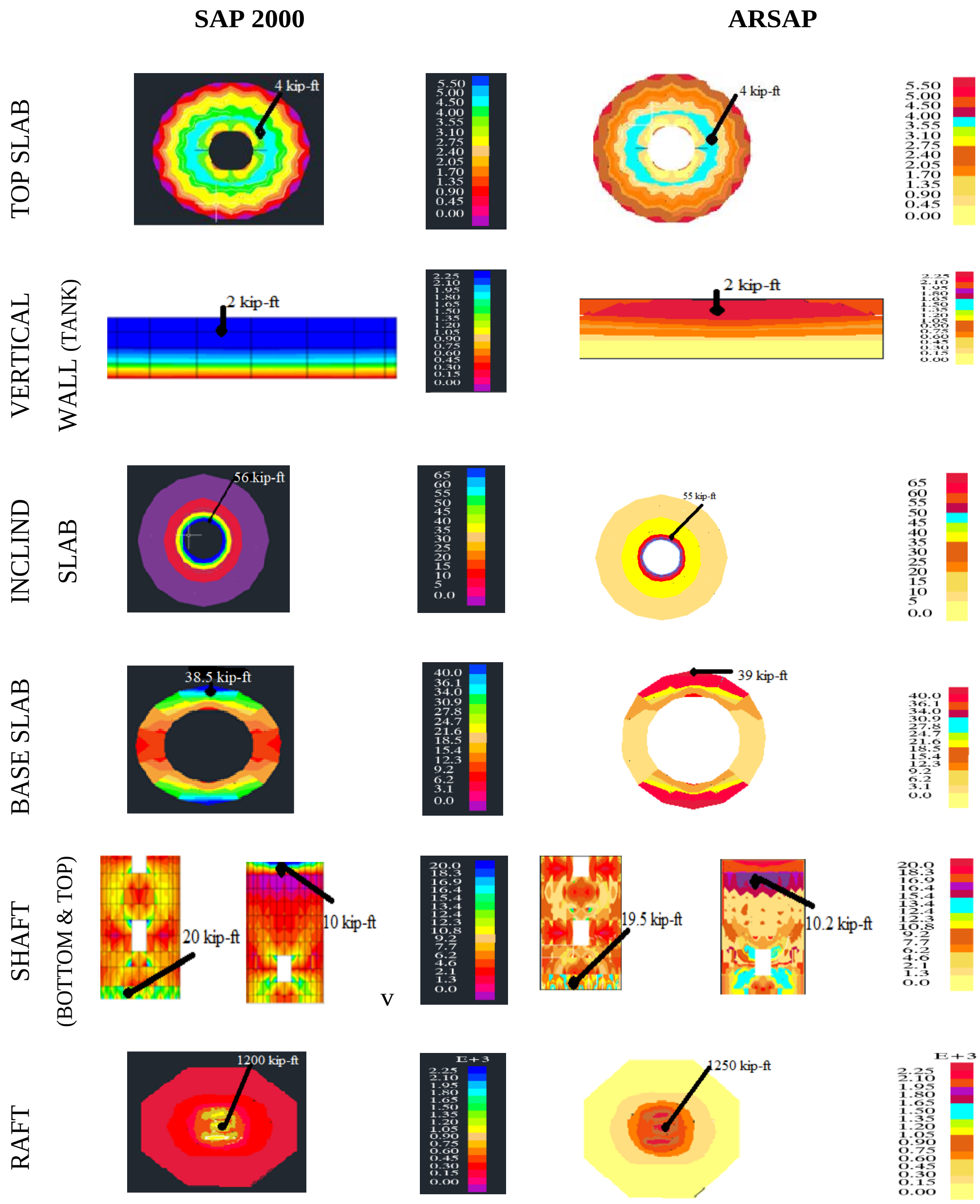


FIGURE 4.3: Bending Moment in different elements of elevated water tank (Zone 2B, Soil profile SE)

In this portion, the trends of moment contours are also similar in both softwares i.e. ARSAP and SAP2000. Another portion that is observed to note the bending moment in the upper portion of the circular shaft of the elevated water tank. In SAP2000, the governing bending moment is observed 10 kip-ft. The maximum bending moment is observed at the top portion of the shaft where shaft of the elevated water tank connects with the water bowl. In this portion, the steel is provided against that moment. In ARSAP, at the upper portion of the shaft, the governing moment is observed 9.80 kip-ft. This moment is governed at the top potion of the shaft, as highlighted in the Figure 4.3 above. The trend of the contours is quite similar in that portion of the shaft in both softwares. These all moments are observed against the soil profile type SE and seismic zone 2B.

The upper member that connects with the shaft of elevated water tank is base slab. The maximum observed bending moment observed in that member is 38.5 kip-ft while analyzing the structure in SAP2000. The soil profile type is SE and seismic zone was 2B while analyzing the structure. The governing moment is observed at the corner of the base slab. The maximum bending moment is noted as 39 kip-ft while the same structure is analyzed in ARSAP. The maximum bending moment is noted at the corner of the inclined slab. The trend of the bending moment is same in both softwares. In both softwares, the analysis the governing moment is at same point as well. On the upper side of the base slab it is connecting with inclined slab. The bending moment at the critical point in inclined slab was noted 56 kip-ft. This value is noted while analysis is done with the SAP2000 software. The maximum value is observed at the inner point of the inclined slab. In ARSAP, the governing moment is noted 55 kip-ft. The bending moment is observed with quite similar trend as in SAP2000 software. The governing bending moment is also observed at inner point of the inclined slab.

A vertical wall adjoined bowl top slab and inclined slab of the bowl. The maximum bending moment is observed 2 kip-ft while the structure is analyzed in SAP2000 and the soil profile type was SE and seismic zone was 2B as well. While the structure is analyzed in ARSAP, the maximum bending moment observed in the vertical wall of the bowl is 2 kip-ft. Which is quite similar with results of the SAP2000. The trend of the contours is also same in both softwares results. The upper element that adjoined the vertical wall is the top cover of the water bowl in which water rests. The maximum moment in the top slab was observed 4 kip-ft while structure is analyzed in SAP2000. In ARSAP, the govering moment is top slab is also 4 kip-ft. The contour trend are also about to same in both softwares.

Table 4.4: Governing bending moments in different elements

Element	Zone 2B					
	SC		SD		SE	
	SAP2000	ARSAP	SAP2000	ARSAP	SAP2000	ARSAP
Raft	900	920	1100	1150	1200	1250
Shaft	12.25	12	16.5	16	20	19.5
Base slab	27	28	34	33	38.5	39
Inclined slab	37	38	47	46	56	55
Vertical outer wall	1.25	1.25	1.5	1.5	2.00	2.00
Vertical inner wall	7	7	9	9.5	12	11
Top slab	2	2	3	3	4	4

Note: All units are in kip-ft.

The governing bending moment is observed in different sections in both softwares are shown above in Table 4.4. The difference in bending moment of elements are negligible towards the steel rebars provision on same soil profile type.

4.4.3 Variation in Analysis of Structural Elements

In this study three soil profile types are used and a constant seismic zone. SC, SD and SE are the three soil profile types which are used in this study. The different parameters of analysis and design are studied in this research. Total six numbers of models are analyzed and designed in this study. Three models are analyzed in ARSAP and three analyzed in SAP2000. The comparison is made for every two models who have same soil profile type and seismic zone. The seismic zone is constant for all models that is 2B. The results of deflection are shown in Figure 4.4 (a). The results on soil profile type SC is consider as 100

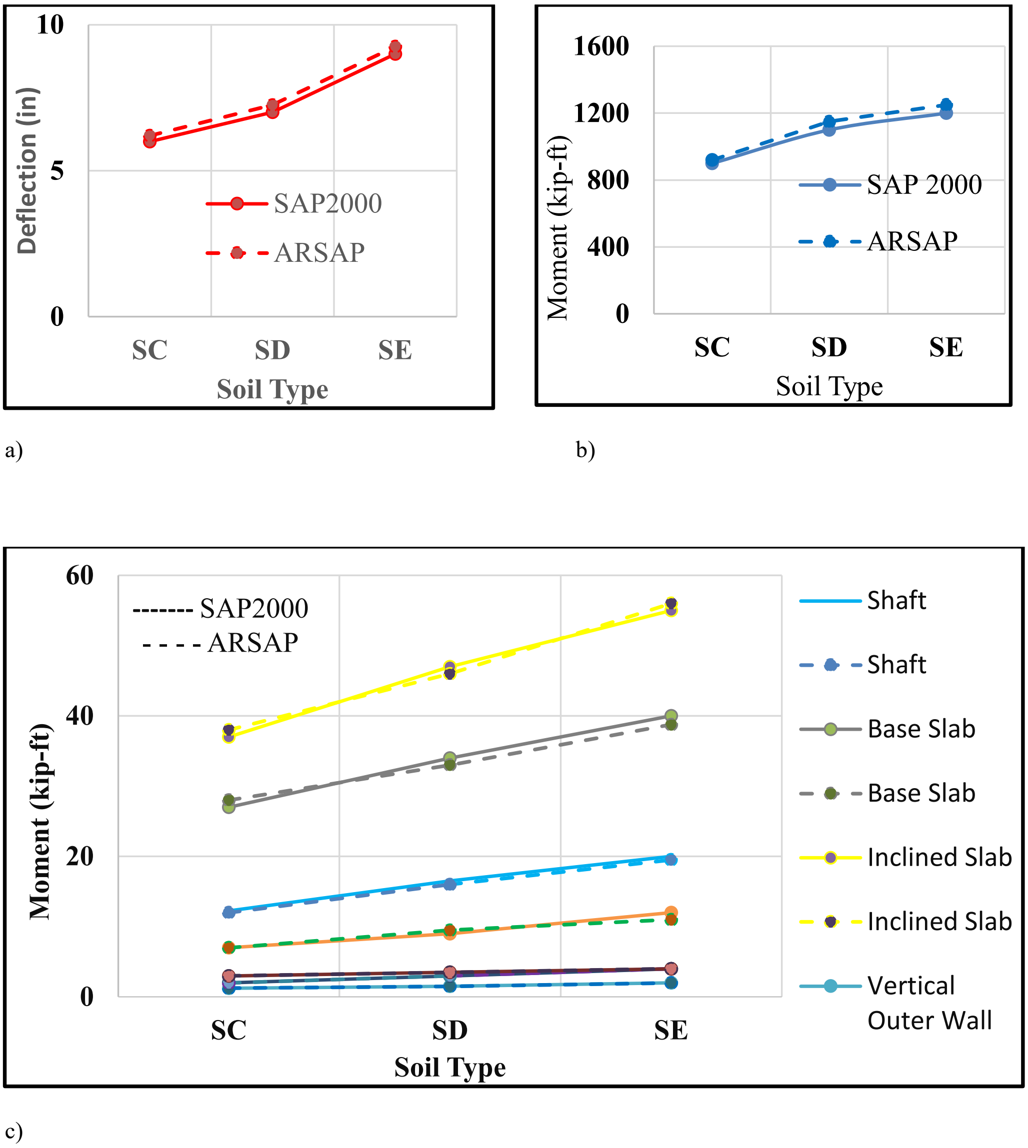


FIGURE 4.4: Variation of analysis (absolute values) of Structural elements of Elevated water tank against different soil profile types. a. max deflection b. Sub structure Bending moment c. Super structure Bending moment

The same soil parameters and seismic zones are considered in SAFE analysis. The maximum bending moment is observed 1200 kip-ft in SAFE software, for soil profile type SE and seismic zone is 2B. The maximum bending moment is observed under the shaft on the raft. While the same structure is analyzed in ARSAP software, the maximum bending moment is observed 1250 kip-ft. There is bit difference in results of both software which is observed in this study. As trend shows in Figure 4.4 (b) the maximum bending moment is observed in soil profile type SE and seismic zone 2B in both softwares i.e. ARSAP and SAFE. The minimum bending moment that is observed in all these soil profile types is against SC in raft. This trend is similar in both softwares. There is slight difference in the results of both softwares which is not much considerable. In Figure 4.4 (b) the doted lines indicate the results obtained from the ARSAP software and the results of SAFE software are shown with the plane blue line. The trend of the results in both softwares is straight line.

The comparison of the elements of the super structure of the elevated water tank are shown in Figure 4.3 (c). All elements are shown for three soil profile types in both softwares i.e. ARSAP and SAP2000. The results of ARSAP are shown with the dotted line and solid lines are used to indicate the result of SAP2000. In Figure 4.3 (C), on the vertical axis the maximum bending moment is labeled and on the horizontal axis the soil profile type is labeled. In shaft while it is analyzed with soil profile type SC the maximum value in SAP2000 is 12 kip-ft. The same element is analyzed in ARSAP the maximum value is noted 12.5 kip-ft. When another model is analyzed with the soil profile type SD and seismic zone is 2B, the maximum value of bending moment is observed 16 kip-ft in SAP2000 and 16.5 kip-ft while this structure is analyzed in ARSAP software. When the third model is analyzed laid in 2B seismic zone and SE soil profile type. The maximum bending moment is observed 19.5 kip-ft and 20 kip-ft in SAP2000 and ARSAP softwares respectively. The trend of the shaft moments in different soil profile regions shows that as structure moves toward SC to SD and then SE the bending moment value increases accordingly. The bending moment of base slab is also shown in Figure 4.3 (c). Same trend for the results of ARSAP is shows with the doted lines and solid lines is shown results of SAP2000. The maximum bending moment observed in soil profile type SC is 27 kip-ft while structure is analyzed in SAP2000 software. In ARSAP, the maximum bending moment is noted 28 kip-ft. The same element is analyzed when in soil profile type SD, the result of SAP2000 is 37 kip-ft and 38 kip- ft observed in ARSAP software. When base slab is analyzed by considered soil profile type SE and seismic zone 2B the results of SAP2000 shows the maximum bending moment 38.75 kip-ft and in ARSAP the maximum bending moment is noted 40 kip-ft.

Inclined slab results are also shown in Figure 4.4 (c) in soil profile type SC, 37 kip-ft in SAP2000 and 38 kip-ft is noted in ARSAP software. The maximum bending moment while the elevated water tank exists in soil profile type SD is 46 and 47.5 in SAP2000 and ARSAP, respectively. The governing bending moment in inclined slab while structure is existing in SE soil profile type is 55 and 56 in SAP2000 and ARSAP, respectively. The bending moment noted in outer vertical wall of the tank is 12 and 12.25 kip-ft in SAP2000 and ARSAP respectively, while structure is existing on soil profile type SC. While the same structure is designed on soil profile type in SD the maximum bending moment is 16 and 16.5 kip-ft in both softwares SAP2000 and ARSAP, respectively. Then the structure is designed on soil profile type SE, the bending moment is noted 19.25 and 20 kip-ft in SAP2000 and ARSAP software. The trend shows that as structure moves toward soft soil bending moment increases in outer wall of the water tank as shown in Figure also. The vertical inner wall of the elevated water tank that exists on soil profile type SC is 7 kip-ft in both softwares i.e. SAP2000 and ARSAP. When structure moves toward SC to SD the 9 kip-ft bending moment is observed in both softwares. After that the soil profile type moves toward SD to SE the maximum bending moment is observed 11 kip-ft in SAP 2000 and 11.5 Kip-ft in ARSAP. The maximum bending moment on the top slab of the elevated water tank while structure is laid on the soil profile type is 2 kip-ft in both softwares i.e. ARSAP and SAP2000. While the structure moved from SC to SD bending moment that is observed in both softwares is 3 kip-ft in top slab of the elevated water tank. When structure is analyzed in soil profile type SE and seismic zone 2B, the maximum bending moment is observed 4 kip-ft in ARSAP and SAP2000. The trend shows that as moving toward lose soil value of moment increases.

The comparison is also made member to member with variation of soil profile type. It is observed that the deflection in the structure that is laying on soil profile type SC is 100% in both softwares i.e. ARSAP and SAP2000 as shown in figure 4.4. The maximum deflection in a structure that is laying on soil profile type SD and SE is noted is 116 and 150%, respectively when it was designed in sap software. these values are noted 115 and 146 % while the structures were analyzed on ARSAP software as shown in Figure 4.5 (a).

The bending moment noted 22% and 33% more while structure was analyzed in sap 2000 and soil profile type SD and SE respectively. And while same models are analyzed in ARSAP then these values increase 10% and 26% on SD and SE soil profile type respectively. . In some elements like top slab and dome, the difference in value of bending moment is just 1 to 2 kip-ft. Due to smaller difference in values this linear trend is observed. Otherwise in terms of percentage the difference is up to 100%.

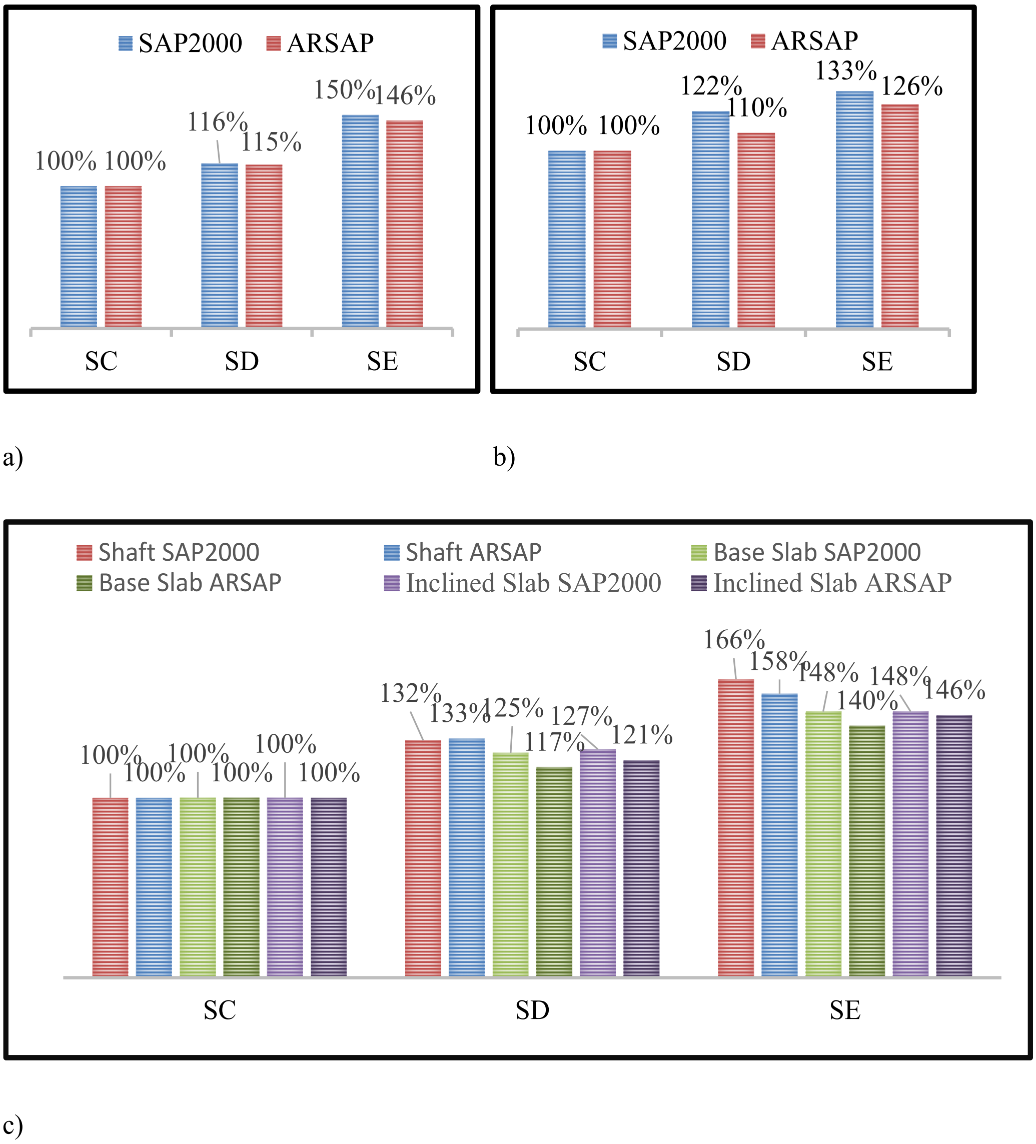


FIGURE 4.5: Variation of analysis of structural elements (percentages) a. Deflection b. Bending moment of raft c. Bending moment of super structure.

The super structure elements are also compared in term of percentages. The moment increased 32% and 66% for structure on soil profile type SD and SE and the software was sap at that time as shown in Figure 4.5 (c). The increment in moment while structure is analyzed in ARSAP is noted 33% and 58% in ARSAP on soil profile type SD and SE respectively. While analysis is done with the help of sap and the member was base slab it is noted that that moments increased up to 25% and 48% in soil profile type SD and SE respectively. And in ARSAP, the increment is noted as 117% and 140% as compared with the result from the structure that rest on soil profile type SC. The moment difference that is noted in inclined slab is 27% and 48% while structure is resting on soil profile type SD and SE and the software is sap2000. The increase in same member is found 21% and 46% on soil profile type SD and SE respectively while the used software is ARSAP.

4.5 Design of Different Elements of Elevated Water Tank

Structural design is carried out by using both softwares i.e. ARSAP and SAP2000/ SAFE. The octagonal shape of raft is decided to provide under all water tanks designed on different soil profile types. The elevated water tank that is designed on soil profile type SE and seismic zone is 2B, in this water tank the width of octagonal raft is 52'. The depth of that foundation is 5.5'. Top and bottom portion of raft is reinforced with different kind of the reinforcement bars. In top reinforcement two types of spacing is used as shown in Table 4.5 concentrated steel is provided under the shaft of elevated water tank and reduced steel is provided in rest portion of the raft. In this raft, bottom steel under the shaft #8 bars of steel is used @3" spacing c/c in both ways.In rest portion same dia of steel is used but the spacing came 4" c/c. . While providing the top steel also used two types of spacing. Under the shaft, #6 bar is used at the spacing of 3" c/c. In rest portion, #5 bar is used and spacing between bars is 6"c/c. While designing the other elevated water tank in which tank is resting on the SD soil profile type. The same shape of the raft is provided under the elevated water tank. In this structure the width of the raft is 43' and its depth is 5'. . In this, the reinforcement is provided at the both sides of the raft i.e. top and bottom.In bottom portion two types of spacing is used one for the undershaft portion and other for the rest portion. The portion under the shaft, close spacing is provided, #8 steel is used @ 4 c/c in both ways and the remaining portion, #8 bars are used #8@8 spacing c/c in both ways. In top reinforcement also two types of reinforcements are used, portion under the shaft #6 steel bars are used and the spacing between these reinforcements is 4c/c in both ways. In reduced portion the top reinforcement is provided #5@7 c/c in both ways.

In third structure, elevated water tank rest on the SC soil profile type. In this design 34 width of the raft is provided and its depth is 4.5. In bottom reinforcement #6 steel is used in concentrated portion on which shaft is resting and spacing of steel between this portion is 3 c/c. In remaining portion same size of reinforcement is used and the spacing is 6 c/c in both ways. In top reinforcement, the two types of the spacing is used for the design. In middle portion where shaft is resting #6 steel bar is used in both ways @ 3 spacing c/c. In reduced portion same dia of steel bar is used but the spacing is 6 c/c as shown in Table 4.5.

The thickness of the shaft is 1 for all the elevated water tanks in both softwares i.e. ARSAP and SAP2000. The elevated water that is designed in seismic zone 2B and on soil profile type SE is provided with #6 bar and the spacing between bars is 8 c/c, transverse steel is provided @8 c/c and the dia of bar is #5. The same thickness of the shaft is considered in the design of elevated water tank that is resting on soil profile type SD and seismic zone is 2B. The longitudinal steel is used #6 @ 8 c/c while transverse steel is used #5 @ 8 c/c as shown in Table 4.5. The elevated water tank that is designed in the seismic zone 2B and the soil profile type SC, in this elevated water tank same thickness and concrete compressive strength is used but reinforcement details are different. The longitudinal steel is provided 10 c/c and the dia of bar is . The spacing between transverse bars are 8 c/c and the #5 bars are used for the transverse steel as shown in Table 4.5. The base slab of 36 is provided over the top of the shaft. Two types of reinforcements are used in the design of this element i.e. ring and circular. The design in which SE soil

TABLE 4.5: Design of structural elements of elevated water tank (i.e. steel rebars)

Element	Location of steel	Thickness	Zone 2B SC	SD	SE
Raft (52' width)	Bottom	5.5'	-	-	#8@3" (under shaft) #8@4 (reduced)
Raft (52' width)	Top	5.5'	-	-	#6@3" (under shaft) #5@6 (reduced)
Raft (43' width)	Bottom	5'	-	#8@4" (under shaft) #8@8 (reduced)	-
Raft (43' width)	Top	4.5'	-	#6@4" (under shaft) #5@7" (reduced)	-
Raft (34' width)	Bottom	5'	#6@3" (under shaft) #6@6 (reduced)	-	–

Continue

			Zone 2B		
Element	Location of Steel	Thickness	SC	SD	SE
Raft (34' width)	Top	4.5'	#6@3" (under shaft) #6@6" (reduced)	-	-
Shaft	Longitudinal	12"	#6@8"	#6@8"	#6@10"
	Transverse		#5@8"	#5@8"	#5@8"
Base slab	Ring	36"	#5@6"	#5@8"	#6@10"
	Circular		#5@6"	#5@8"	#6@10"
Bowl Inclined Slab	Radial (top & bottom)	Max 18" Min 15"	#5@4"	#5@4"	#5@4"
	Circular (top & bottom)		#4@6"	#4@6"	#4@6"
Tank outer wall	Vertical	12"	#5@6"	#5@8"	#4@8"
	Circular		#4@6"	#4@9"	#4@12"
Tank inner wall	Vertical	12"	#5@6"	#5@8"	#4@8"
	Circular		#4@6"	#4@6"	#4@8"
Tank Slab	Bottom	9"	#4@6"	#4@6"	#4@6"
					Continue

Element	Location of Steel	Thickness	Zone 2B SC	SD	SE
	Top at ends		#4@6”	#4@6”	#4@6”

Note: since there is marginal difference between bending moment obtained from SAP2000 and ARSAP, design is being carried out with larger moment which is applicable for other also.

profile type is considered, #5 bar is used and the spacing between bars is provided 6 c/c for both kind of reinforcement. The elevated water tank that rests on soil profile type SD, the reinforcement that is provided in base slab is #5 @ 8c/c for both reinforcements i.e. ring and circular. The last structure that is designed on soil profile type SC the reinforcement in the base slab of that structure is reinforcement with #6 @ 10 c/c for both kind of reinforcements.

The bowl inclined slab is provided at same depth in the all structures that is designed on different soil profile types as shown above in Table 4.5. The elevated water tank that is designed over the soil profile type SE, the top and bottom radial reinforcement is provided #5 @ 4 c/c. And the reinforcement in circular pattern in both portions (top and bottom) is provided #4 @ 6c/c. As shown in Table 4.5, same reinforcement detail as of SE is provided in all elevated water tanks in different seismic zones as well as softwares i.e. ARSAP and SAP2000. Another element of elevated water tank is the design of tank outer wall. The thickness of that element kept same in all models i.e. 12, but reinforcement detail is different. The water tank that exists on soil profile type SE has reinforcement detail #5 @ 6 in vertical manner and #4 @ 6 in circular manner. The other elevated water tank that exists over the soil profile type SD is provided with the #5 @ 8 in vertical directions and #4 @ 9 c/c in circular direction. The tank that rests on the soil profile type SC is provided with vertical reinforcement #4 @ 8 c/c in vertical direction and #4 @ 12 in circular direction. The 12 thick inner tank wall is also provided with same dimensions but reinforcement detail is different. The tank on SE provided with #5 @ 6 in vertical and #4 @ 6 in circular directions. The structure that is resting on SD is reinforced with #5 @ 8 and #4 @ 6 in vertical and circular directions respectively. Another tank that exists on SC soil profile type is provided with #4 @ 8 steel in both directions. Top slab of 9 thickness is provided and #4 @ 6 c/c is provided in all structures as shown in Table 4.5.

4.6 Limitation of SAP and ARSAP for Analysis and Design of Elevated Water Tank

There may be many drawbacks of both softwares used in this study i.e. SAP2000 and ARSAP. The SAP2000 and ARSAP works only node to node. That is why the analysis of the elevated water which is made of brickwork pedestal is not possible to analyze in these softwares. The P-delta effect is not considered in the modelling when the elevated water tower is modelled in both softwares i.e. SAP2000 and ARSAP. Mass source is assumed as load in both softwares.

There are fixed characteristics of ground motions under consideration while analyzing an elevated water tank by using both softwares i.e. ARSAP and SAP2000. The linear design is carried out by using these earthquake ground motions. Although there are many locations in world which does not match with these conditions. The deflected shapes of the structure can be noted against different load cases and load combinations. The maximum value can be checked against any load case or envelope. These can also be checked manually. In sap2000, bending moment contours are displayed on the screen and governing bending moment will be selected by the designer. There is a chance of error while reading that value. In ARSAP, there is an option in which bending moment can be obtained in regular regions, In that portion a governing bending moment is used throughout the region. There is a chance of error while reading this bending moment.

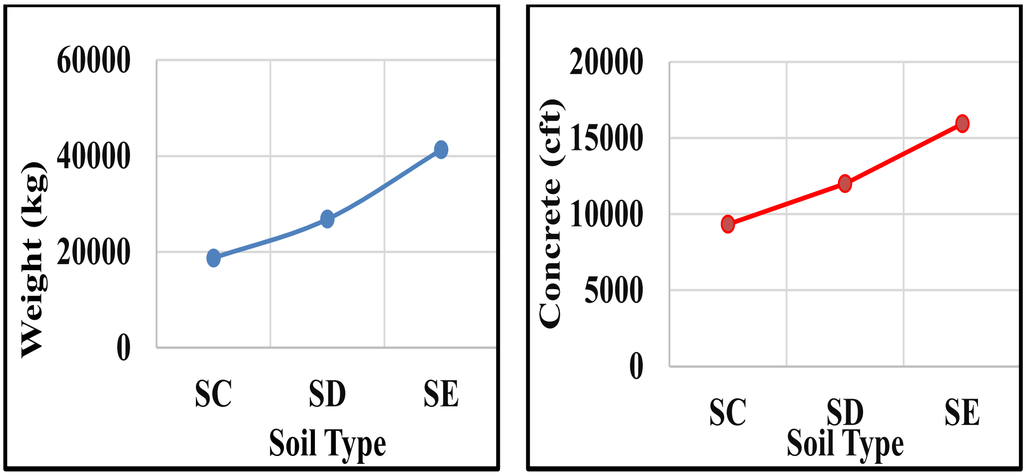
Design output is very important aspect of analysis and design of any structure. While a structure is analyzed by using SAP2000 software the design output are generated separately. Which takes a lot of time and need special expertise to produce design output or structural drawings. In this practice, the moments are noted from the sap software and manual or with the help of excel spread sheets, the rebars are calculated and again structural drawings are made by using auto cad software. Which requires experts in AUTOCAD software and time as well. The production of structural drawings which are executable on site is missing in sap software. This is the major drawback of the sap2000 software. While an elevated water tank is analyzed on ARSAP software, architectural drawings are made by using revit architecture software and then these drawing are shifted to the robot software for the analysis and design. After analysis, ARSAP is not much capable to produce such kind of structural drawings which are directly executable on site.

4.7 Estimation

The estimation of elevated water tank is done. The difference in bending moment from both softwares is very less. The marginal governing bending moments from both softwares are taken. Economy can be achieved by reducing material and accelerating speed of construction or by the use of both approaches. Therefore, in this research (design) rebars selection is done in such a way to achieve maximum speed of construction. By keeping in view capability of available skilled labour in Pakistan. The quantity of steel and concrete that is provided on different soil profile types are calculated as shown in Table 4.6. The elevated water tank that is resting on soil profile type SC, the estimated steel quantity is 18719 kg and the estimated concrete volume is 9818 cft. The elevated water tank that is resting on the soil profile type SD, in this structure the estimated steel quantity is 26824 kg and the estimated concrete volume is 11997 cft. The structure that is resting on loose soil SE in this the estimated steel quantity is 41291 kg and the estimated concrete volume is 15931 cft.

TABLE 4.6: Estimation of quantities

	Zone 2B		
Material	SC	SD	SE
Steel (kg)	18729	26824	41291
Concrete (cft)	9318	11997	15931



a) b)

FIGURE 4.6: Variation in Estimation a. Steel b. Concrete

The graphical relation between the estimated quantities against the different soil profile types are shown in Figure 4.6. In Figure 4.6 (a) the calculated of steel against different soil profile types are shown graphically. And in Figure 4.6 (b) the concrete volume is shown graphically against three soil profile types i.e. SC, SD and SE.

The variation in estimation in term of percentage is shown in Figure 4.7. In Figure 4.7 (a) the variation against different soil profile types of steel is shown in term of percentage. The Structure that is resting on soil profile type SC is taken as reference and its values is taken as 100%. The steel used in structure that is resting on soil profile type SD is 43% more than the structure that is resting on soil profile type SC. Similarly, the water tank that is resting on soil profile SE the estimated steel is 120% more as compared with SC. The difference in term concrete volume is shown in Figure 4.7 (b). The elevated water tank the is resting on soil profile type SD, volume of concrete estimated is 28% more than SC soil profile type. The structure that is on soil profile type SE the estimated concrete volume is 71% more as compared with soil profile type SC.

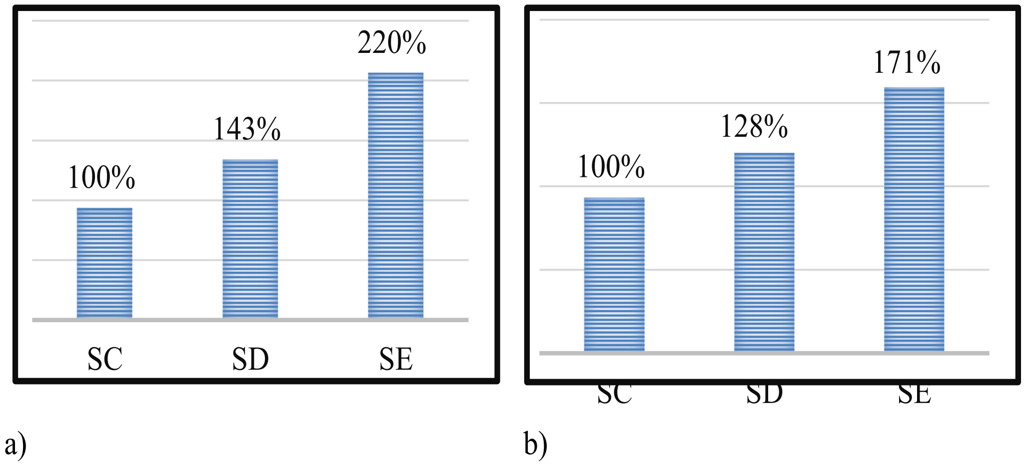


FIGURE 4.7: Variation in estimation (percentage) a. Steel b. Concrete

TABLE 4.7: Estimation of cost

Material	Zone 2B					
	SC		SD		SE	
	Quantity	Price*	Quantity	Price*	Quantity	Price*
Steel (kg)	18729	144467	26824	1114354	41291	318500
Concrete (1:2:4) (cft)	5807	2334414	8486	3411372	12420	4992840
Concrete (1:1.5:3) (cft)	3511	1311183	3511	1311183	3511	1311183
Pak Rupees	Total	6790064	Total	12836909	Total	21622523
Cost in Million		6.79		1.28		2.16

The cost estimation is also done by using MRS Rawalpindi (2020 1st). The estimated cost of the structure that is resting on different soil profile types is shown in Table 4.7. Elevated water tank that is on soil profile type SC is calculated 6.79

million of Pakistani rupees. While the structure that is resting on soil profile type SD, the estimated cost is 12.84 million. Elevated water tank that is resting on loose soil i.e. SE the cost will increase up to 21.62 million as shown in Table 4.7.

4.8 Summary

In this chapter, firstly emphasize is on time period and base shear of the elevated water tank that exists on different soil profile types and the comparison of the results of different structural softwares. Then the external stability checks are satisfied. After that deflected modes and shapes are discussed in detail. Then the bending moment is discussed of different elements of the elevated water tank in both softwares. In the end of the chapter the design is explained and which type of structural steel is provided is explained in detail.

Chapter 5

Conclusion and Future Work

5.1 Conclusion

The overall purpose of the research is to provide safe design of elevated water tanks with new and emerging softwares. In developing country, mostly conventional approaches are used for the design of elevated water tanks or other important structures. This pilot study, in which comparison is made for the detailed design of elevated water tank in different softwares i.e. SAP2000 and ARSAP. The seismic zone is same in the design of elevated water tank in both softwares but different soil profiles types are used while comparing the results of both softwares. Following conclusions can be drawn from this study.

- Comparison of both softwares shown that the difference in the output is very less and ignorable in term of steel provided in different elements of the elevated water tank.
  - In ARSAP less analysis time is required as compared with SAP 2000.
  - In ARSAP model can be edited using Excel sheets and those changes can be represented in Robot Model.
  - The production of structural drawing that are executable on site is missing from both softwares.

- A slight difference is observed in both softwares results while analyzing the elevated water tank.
    - Deflection is noted against envelope and found slight difference in maximum deflection.
    - Bending moment is observed from contours and margional difference is found from the both softwares results.
    - It is observed that maximum deflection is noted that structure is resting on soft soil and minimum is observed the water tank that is rest on good soil SC.
- It is noted that the raft that is resting on good soil have less area as well as depth.
- Super structure elements are also shows that the maximum steel is provided in that structure that is resting on soft soil.
- The production of structural drawing that are executable on aite ia miaaing from both softwares.

5.2 Future Work

This work was the first step to explore the in-depth behavior of elevated water tanl by using ARSAP software for the design of elevated water tank. Next steps should be:

- Exploration on BIM tool, regarding structural drawings and steel calculations on one click from BIM.
- Non-linear analysis and design of elevates water tank by using ARSAP.

Bibliography

[1] S. Soroushnia, S.T. Tafreshi, F. Omidinasab, N. Beheshtian, and S. Soroushnia, "Seismic performance of RC elevated water tanks with frame staging and exhibition damage pattern," *Procedia Engineering*, vol. 14, no. 2 pp. 3076-3087,2011.

[2] M. Eswaran, U.K. Saha, and D. Maity, "Effect of baffles on a partially filled cubic tank: Numerical simulation and experimental validation," *Computers & Structures*, vol. 87, no.3, pp. 198-205, 2009.

[3] S. A. Barakat, and S. Altoubat, "Application of evolutionary global optimization techniques in the design of RC water tanks," *Engineering Structures*, vol. 31, no. 2, pp. 332-344, 2009.

[4] J. Ferrandiz, A. Banawi, and E. Pena, "Evaluating the benefits of introducing "BIM" based on Revit in construction courses, without changing the course schedule," *Universal Access in the Information Society*, vol. 17 no. 3, pp. 491-501, 2018.

[5] Aram, M.Fischer, D.Endy, T. Moore, and A. Sorgo, "Can we grow buildings? Concepts and requirements for automated nano-to meter-scale building," *Advanced engineering informatics*, vol. 25 no. 2, pp. 390-398. 2011.

[6] R. Ren, J. Zhang, & H. N. Dib, "BIM Interoperability for Structure Analysis," *In Construction Research Congress*, vol. 1. pp. 470-479. 2018.

[7] D. Johnson, and M. Sirajuddin, "Behaviour of Elevated Water Tank under Seismic Load-Review," *Behaviour of structures*, vol. 5, no. 5, pp. 410-417, 2018.

[8] K. V. Steinbrugge, and A. R. Flores, "The Chilean earthquakes of May, 1960: A structural engineering viewpoint," *Bulletin of the Seismological Society of America*, vol. 53, no. 2, pp. 225-307, 1963.

[9] R. Ghateh, M. R. Kianoush, and W. Pogorzelski, "Seismic response factors of reinforced concrete pedestal in elevated water tanks," *Engineering Structures*, vol. 17, no. 3, pp. 32-46, 2015.

[10] K. V. Steinbrugge, and A. R. Flores, "The Chilean earthquakes of May, 1960: A structural engineering viewpoint," *Bulletin of the Seismological Society of America*, vol. 53, no. 2, pp. 225-307, 1963.

[11] A. M. Memari, M. M.Ahmadi, and B. Rezaee, "Behaviour of reinforced concrete water towers during Manjil-Roudbar earthquake of June 1990," *In Proceedings, 10th World Conference on Earthquake Engineering*, vol. 2, pp. 487-495, 1993.

[12] D. C. Rai, "Review of code design forces for shaft supports of elevated water tanks." *In Proceedings of 12th symposium on earthquake engineering*, vol. 1 pp. 1407-1418, 2002.

[13] R. Ghateh, M. R.Kianoush, and W. Pogorzelski, "Seismic response factors of reinforced concrete pedestal in elevated water tanks." *Engineering Structures*, vol. 87 no. 2, pp.32-46, 2015.

[14] R. J. Aware, and D. V. S. Mathada, "Seismic Performance of Circular Elevated Water Tank," *International Journal of Science and Research (IJSR) ISSN (Online)* , pp. 2319-7064, 2016.

[15] B.Lallotra, and D. Singhal, "State of the Art Report-A Comparative Study of Structural Analysis and Design Software-STAAD Pro & SAP-2000 Software," *International Journal of Engineering and Technology*, vol. 9, no. 2, pp. 1030-1043, 2017.

[16] A. Moulik, D. Tiwari, and R. Chandak, " RELATIVE STUDY OF SEISMIC BEHAVIOUR OF INTZE TANK HAVING DIFFERENT TYPES OF STAGING WITH SAP2000" *Journal of Engineering and Technology*, vol. 9, no. 1, pp. 130-143, 2016.

[17] A. Shahbazian, and S. Pezeshk, "Improved velocity and displacement time histories in frequency domain spectral-matching procedures," *Bulletin of the Seismological Society of America*, vol. 100 no. 6, pp. 32133223, 2010.

[18] S. Soroushnia, S. T. Tafreshi, F. Omidinasab, N. Beheshtian, and S. Soroushnia, "Seismic performance of RC elevated water tanks with frame staging and exhibition damage pattern," *Procedia Engineering*, vol. 14, no. 1, pp. 3076-3087 2010.

[19] M. Yang, I. C. Wu, L. Allan, and C. J. Ku, "The Module of Rebar Modeling for Chinese Building Standard," *In Proceedings of 17th symposium on earthquake engineering*, vol. 1 pp. 1807-1817, 2011.

[20] Adekristi, and M. R. Eatherton [2015] "Time-Domain Spectral Matching of Earthquake Ground Motions using Broyden Updating," Bulletin of the Seismological Society of America 100(6), 32133222.

[21] S. A. Barakat, and S. Altoubat, "Application of evolutionary global optimization techniques in the design of RC water tanks," *Engineering Structures*, vol. 31, no. 2, pp. 332-344, 2009.

[22] S. Beardsley, A. Stochetti, and M. Cerone, "The Design of Akhmat Tower," *In E3S Web of Conferences* Vol. 33, no. 1, pp. 1022-1034, 2018.

[23] S. P. Chakraborty, S. Kundu, A. Roy, B. Adhikari, and S. B. Majumder, "Effect of Jute as Fiber Reinforcement Controlling the Hydration Characteristics of Cement Matrix.," *Industrial & Engineering Chemistry Research*, vol. 52, no. 1, pp.12521260, 2013.

[24] M. Eswaran, U. K. Saha, and D. Maity, "Effect of baffles on a partially filled cubic tank: Numerical simulation and experimental validation," *Computers & Structures*, vol. 87, no. 4, pp. 198-205, 2009.

[25] J. Hancock, J. Watson-Lamprey, N. A. Abrahamson, J. J. Bommer, A. Markatis, E. McCoy, and R. Mendis, "An improved method of matching response spectra of recorded earthquake ground motion using wavelets," *Journal of Earthquake Engineering*, vol. 10 no. 1 pp. 6789, 2006.

[26] F. Naeim, and M. Lew, "On the use of design spectrum compatible time histories,"