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Seismic Analysis of Partial and Fully Underground Building on Various Analytical Software: A Literature Review

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ABSTRACT

Increasing number of under the ground facilities such as underground metro stations, underground water tanks, parking facilities, nuclear powerhouses, underground civil facilities, underground shelter for war time and various others. Hence, it has become necessary for safety aspect that these structures are safe for Earthquake point of view. Though, it is also taken into consideration that underground structures are less suspect to earthquake waves in comparison to above the ground structures. Hence, It will be beneficial to built underground structure. Various authors has studied in this field includes comparative behavioral study of underground water tank and above ground water tank etc. Hence, this paper reviews various authors study related to underground facilities using various software. Therefore, It is concluded that since increasing number of underground facilities due to congestion in urban areas, research needs to be put on to design and analysis of underground buildings.

Keywords: structure, underground, seismic, parking, powerhouse, nuclear facilities.

1. Introduction

Subsurface Development is not a new technology which has become part of recent construction developments. Earlier also it was part of people's lifestyle in terms of Caves and Grottos, caves as temples and Monasteries, Caves as Dwellings and various others. Among these one of the developments was water tunnels called as "qanat in Arabic" and "karez in Persian". Another development was transportation tunnel, excavated by Babylonians beneath Euphrates river. It was an underpass for pedestrians. On the same line railway tunnel and road tunnels was built. In turkey, there are 23 large scale underground cities in Cappadocia region. While, in india, earliest examples of underground structures were in form of dwelling pits in Kashmir. 17 basement chamber found below the Taj Mahal at Agra, UttarPardesh [1-2].

Despite of these steps, in china, more than 2 million m^2 sub surface developments as underground buildings taken place. Also, a document called " Going Underground" published by Royal Swedish academy of engineering sciences describes uses of underground space. In recent developments, a underground ice hockey stadium with a span of 60 metre built for 1994 winter Olympic games at Norway. While, in India, Palika Bazaar, an underground market at New Delhi. This market is built as cut and cover Subsurface structure. Also, at New Delhi, various Underground Parking Facilities has been planned for construction. Figure 1 shows top cities with longest metro and sub way systems and Figure 2 shows growth of subway systems from year 1870 to 2010 [1-2].

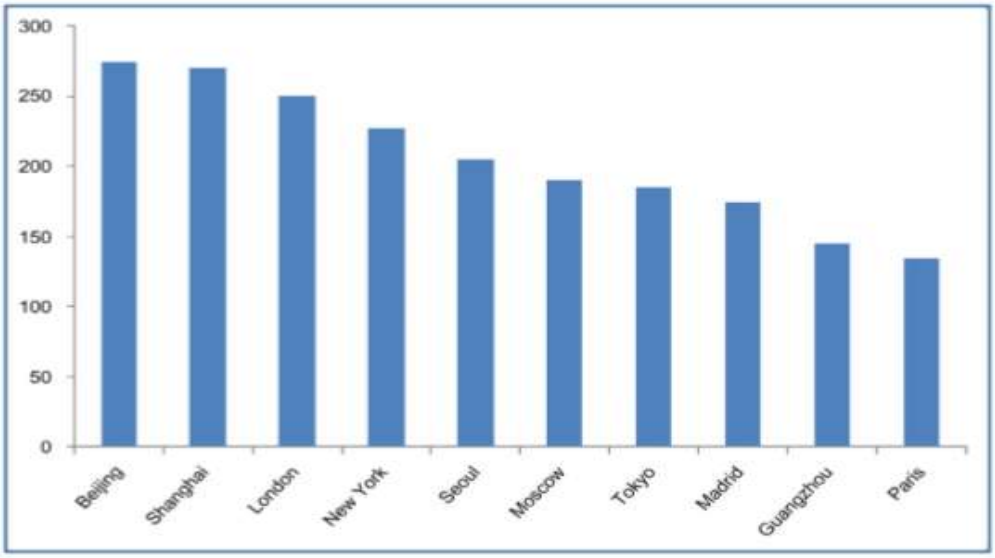

Figure 1. Cities having longest metro and subway systems [2]**.**

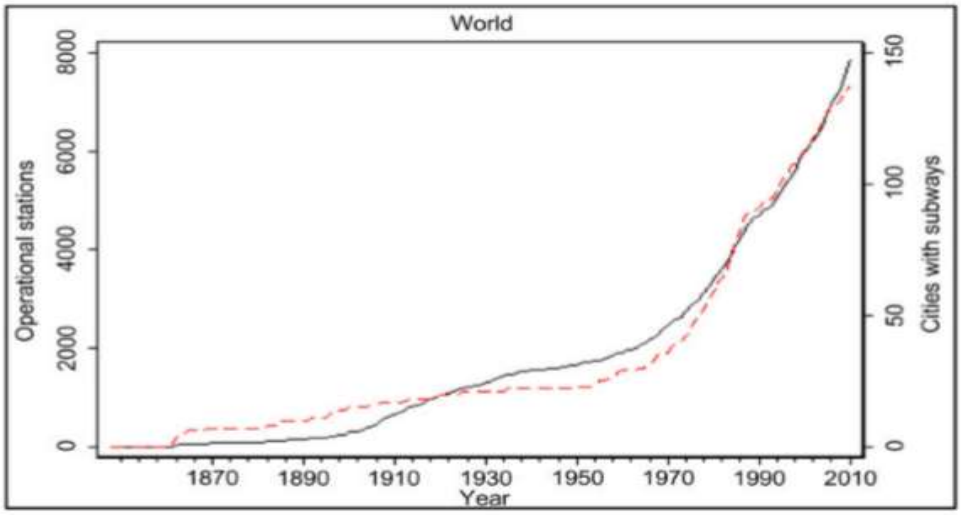

Figure 2. Progress of underground facilities construction [2].

From Figure 2, it has become clear that adoption of underground space development has increased with time. Based on that underground facilities classified as shown in figure 3. Increasing number of underground facilities are mainly due to land use efficiency, Energy conservation, Disaster readiness, less construction disruption, sale of excavated materials, protection from noise and explosion.

Classification of Underground Space Use by Depth

Term	Typical Range of Depth Implied According to Use (m)			
	Local Utilities	Buildings	Regional Utilities/ Urban Transit	Mines
Shallow	0–2	1–10	0–10	0–100
Moderate depth	2–4	10–30	10–50	100–1000
Deep	>4	>30	>50	>1000

Figure 3: Classification of Underground Facilities based on Depth [2]

Another parameter planning and designing which is taken into consideration in every projects. Therefore, underground infrastructure planning and its designing is also a major aspect. For instance, in Japan, on the basis of land ownership, uses of underground space is taken into consideration, shown in figure 4. While, figure 5 discusses design procedure for any underground structures.

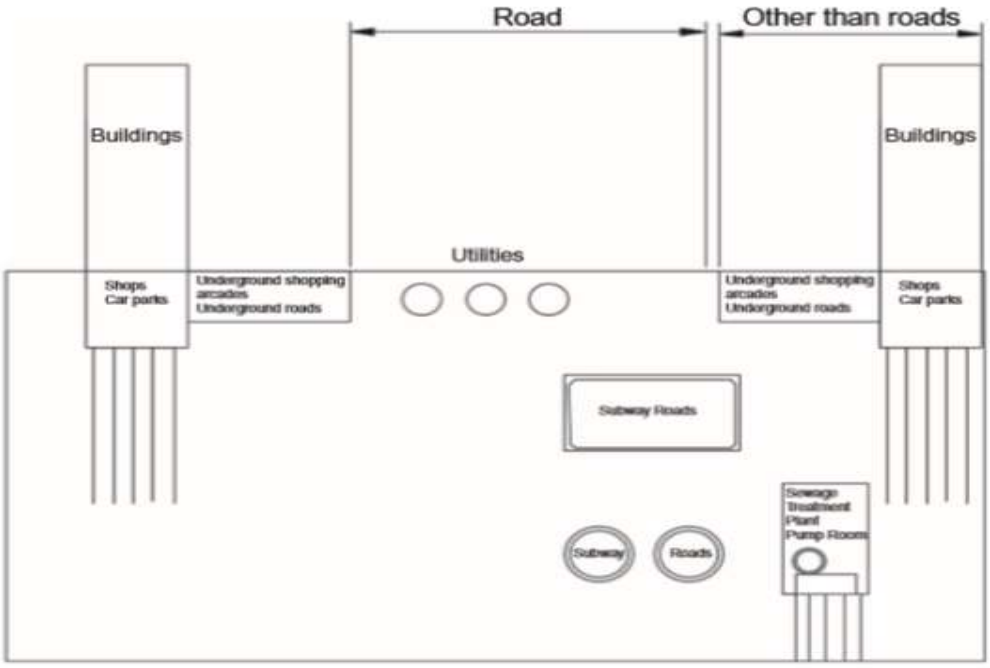

Figure 4: Underground Space in Japan [2]

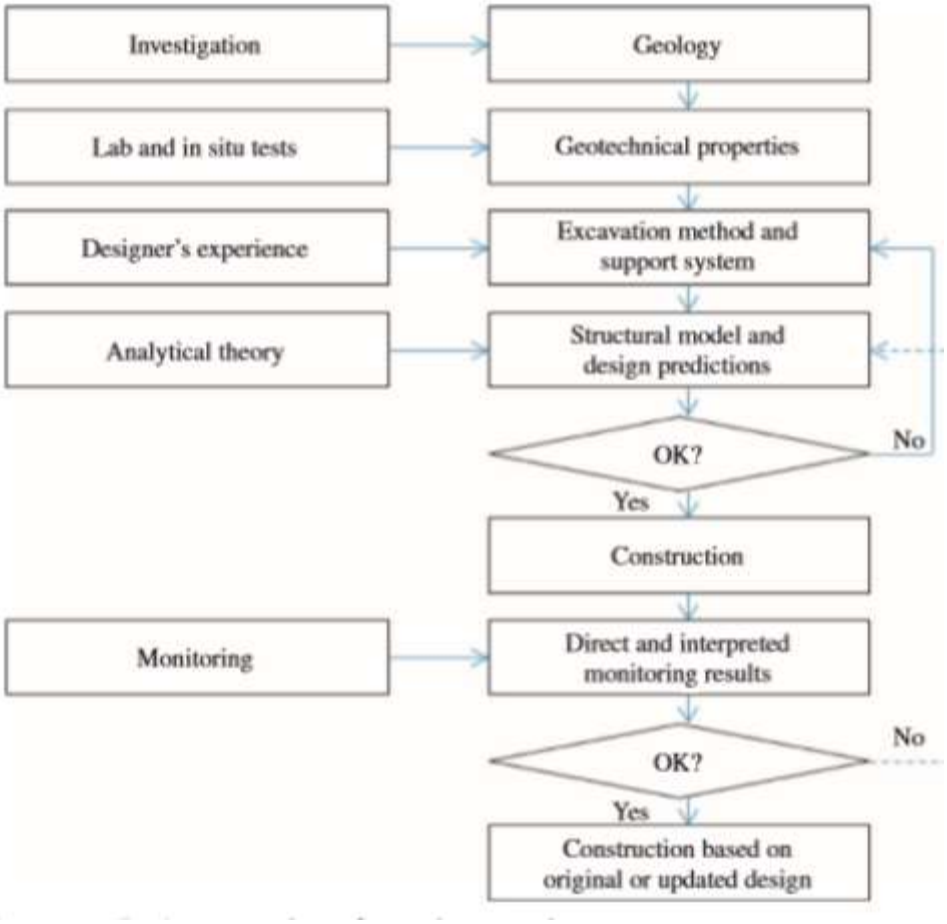

Figure 5. General Procedure for Design of Underground Infrastructures [2]

Despite of taking all the important parameters taken into consideration for underground infrastructures such as planning and design aspects. Earthquake parameter which is also taken into consideration for all underground structures design. Though various studies has been conducted shows that underground infrastructure is not prone to earthquake. But, with time, it is found that underground structures are less prone to earthquake in comparison to above ground structures, but not fully safe. Hence, while designing , it is concluded that these structures need into consideration for seismic aspect. Therefore, this paper reviews various study conducted in this area of underground facilities using various Finite Element Softwares (FEM) such as STAAD PRO, ANSYS, ETABS, SAP 2000 and various others.

2. Literature Review

Anshuman S. et al.(2011): Study has conducted using STAAD Pro 2004 and SAP 2000 software. Research conducted in zone IV and earthquake forces is calculated and applied to fifteen storeys of building. It has been concluded that shear wall need to be provided in 6^{th} and 7^{th} frames or 1^{st} and 12^{th} frames in shorter direction[3]**.**

G. Saad et al. (2012): This paper studies seismic analysis of underground structure having number of storey was present below the ground. It advices for analysis of shear wall building design, number of underground storey need to be taken into account. To know the effect of soil structure interaction, three paprameters was calculated- base shear, inter storey shear and moments[4].

Yiouta-Mitra P. et al. (2013): Study deals with to what extent underground structures is taken into account for earthquake resistant design of neighboring above ground structures. For further study, dynamic plane numerical analysis is conducted. it is found that Stiffer linings generally increases the effect of the tunnel presence on the ground response [5].

Rajesh Jayarambhai Prajapati et al.[5] (2013) Research has been conducted on ETABS V9.5 software to check the impact of different positions of shear wall on deflection in high rise building. It has been concluded that there was minute reduction in deflection, by introducing side center but decrease in deflection was more when shear wall introduced at corner along both direction [6].

Jaywant J. Madane et al. (2014): It highlights various studies conducted on RCC building, built underground, having shear wall. And study proposes seismic behavior of underground parking with ideal location of shear wall. It concludes that building with shear wall deflects less as compared to without wall[7].

Anup Y Naik et al. (2015): Study conducted on RCC reservoir which is completely buried. Seismic analysis was done for reservoir using SAP (2000). Rectangular tank is analysed for seismic forces in two of the perpendicular direction and influence of these forces at different level of water tank was conducted [8].

Sunil J. Payghan et al. (2015): Underground rectangular RCC tunnel was analysed using STAAD pro. It is concluded that stresses, displacement, moments, forces, and reactions increases in tunnel when subjected to seismic forces.it is suggested that lateral and shear forces need to be taken into consideration while designing tunnel [9].

A. Brito et al. (2015): This paper discusses about design of seismic underground building (4 -storey). Study shows comparison between eurocode EC (part-1)-2004 and methodology proposed by author. Paper discusses capacity based method for design purpose. Hence, it is concluded that proposed methodology is applicable in increasing lateral deformation capacity of structure. The structure´s deformation capacity is evaluated by means of static monotonic nonlinear analysis[10].

Anoop Singh et al. (2016): STAAD Pro software was used for seismic analysis of G+10 building. Storey drift, member forces, joint displacement and support reaction was evaluated for the building. It is found that building is safe for Zone II. Maximum drift was 2.077 cm. displacement of beam is with in the limit of Indian standards [11].

Chaitaniya Patel et al. (2016): Seismic analysis of RCC building is analyzed having multiple storey underground built. It also aims to review the impact of soil subgrade modulus. For this purpose, STAAD PRO software was used. It concludes that by increasing underground storey's, variation in soil subgrade modulus effects reduces. As it is known that soft soil consist of high soil subgrade modulus. While this modulus depends on stiffness of foundation and number of underground storey[12].

Shalini A. Thawrani Et al. (2016): this study deals with the effect of earthquake forces on underground structures. Soil structure ineraction is also taken into account in this study. It concludes that underground structures should be designed for ground deformation rather that inertial forces. Longitudinal seismic analysis should be carried out along with transverse analysis. For soil interaction analysis, time history analysis using 3D FEM software was should be carried out [13].

Mohammed Azgar et al. (2017): circular overhead water tank analysed using STAAD pro Software. It is found that there was little variation in design values of software and in manual calculations. Hence, it is suggested that designer can not provide less that the values, get from program [14].

Magdy. M. M. Genidi et al. (2017): Study conducted to determine the seismic effect on underground floors using ANSYS and CivilFEM. It is found that the story shear of building structure may be significantly underestimated if the underground floor(s) of the building is ignored in the analysis. The lateral displacements of building structure may be significantly underestimated if the underground floor(s) of the building is ignored in the analysis [30].

Raman R. et al. (2017): Study highlights seismic analysis in designing of underground structures of hydro power projects. For this purpose, RS2 software was was used to evaluate seismic effects on underground caverns. It concludes that with seismic loading, increment is seen in maximum axial forces on lining. It recommends for soil structure analysis while designing underground cavern[15].

Eshwarayya BL et al. (2018): This paper discusses earthquake analysis and design of underground structures. For study of Racking deformation of underground metro station box at Bangalore is analysed using PLAXIS 8.2 Software. And later, it was analyzed analytically. Racking deformation obtained for rectangular tunnel using software and analytical method is found to be nearly equal [16].

Anshuman Nimade et al. (2018): Underground water tank was analysed using FEM. Under FEM, STAAD pro software was used. It aims to study behavior of underground water tank for varied L/B ratio. Node displacement and stress pattern was also taken into consideration. Empty and full condition of tank was considered [17].

Abhinandan R. Gupta et al. (2020): underground pipeline was analysed in different seismic zones using STAAD Pro. Four cases was modeled and analysed with pipeline made of same material. It is found that plate shear stresses are greater for above pltes as compared to middle plates. Also, there was little change in magnitude with change in seismicity [18].

ZHENG Guodong et al. (2020): This study introduces correlation effects of underground subway, soil and nearby existing structure during earthquake. Simulation was done on ANSYS [19].

Rahul Dubey et al. (2021): Seismic analysis of underground water tank was conducted based on soil structure interaction using ETABS 17 software. It is found that shear force influence the thickness of wall. While soil structure interaction taken into account , design forces increases in comparison to seismic design of tank with rigid base[20].

Sneha V. Dhanawade et al. (2021): Study conducted using STAAD Pro to analyse underground and elevated reservoir. It is found that lateral displacement in tank due to wind is critical. Base shear in empty condition is more than full condition. Natural frequency decreases with increase in water storage[21] .

Komal K Wagh et al. (2021): Underground water tank was analysed using STAAD Pro software. IS 456-2000 and SP-16 was used for reference. Limit state design method was used for design purpose. It is found that there was total 15-20% saving in steel [22].

Sun-Yong Kwon et al. (2021): This research describes dynamic numerical analysis for deep underground structures. In this paper, PLAXIS 2D software is used. Also, dynamic behavior of underground building structure was evaluated. In conclusion, results was compared with centrifuge test data for verification. While centrifuge test conducted in dry dense sand condition [23].

Diksha Gupta et al. (2022): Response spectrum method was used to conduct seismic analysis of multistory building for different zones. Later, these building analysis was compared using STAAD Pro. Various parameters such as base shear, storey drift and storey displacement was also evaluated [24].

Yogendra Borkar et al. (2022): ETABS 18 software was used to seismic analyse the underground, above the ground and elevated water tank on different soil condition. Total 9 cases was analysed using response spectrum method. Base shear, base moment and storey drift was also obtained. It is found that Drift is decreases with increases in stiffness of soil for all water tanks [25].

Ande SOWMYA et al. (2022): Seismic analysis of G+12 RCC building was conducted using ETABS software.comparision is made on static and dynamic method of analysis.it is found that storey drift is slightly higher in Y direction than in X direction [26].

Deepshikha Gadekar et al. (2022): STAAD pro software was used to analyse the underground water tank for different fill condition. It is concluded that shear force rise by 8% in fill condition. In empty condition axial force value declined by 14%. There was 11% variation in full condition for support condition in compare with empty condition [27].

Akash Upadhyay et al. (2023): STAAD Pro software was used to analyse underground circular and rectangular water tank. It is found that more shear force obtained in rectangular water tank than in circular water tank. Greater moment in circular tank than in rectangular tank. Axial force found to be same in rectangular tank for empty and full condition while same in circular tank in full condition [28].

Harshad Nahalde et al. (2023): Seismic analysis of underground water tank was conducted using STAAD pro. Fot filled and empty state, there was increase in bending moment for both rectangular and circular tank. It has been seen that there was considerable rise in shear force for both tanks. In both cases, it was concluded that pressure inside the wall depend on hydraulic and backfill condition[29].

3. Conclusion

It is concluded that various authors have presented their study using different softwares such as STAAD pro, ETABS, ANSYS, PLAXIS and others. Their study generally varied from various sub areas of underground facilities such as analysis of underground water tank, multi storey buildings, racking deformation, underground RCC tunnels and others. But, these study consist research gap which needs to be fulfilled because with the increase in adopting trends of underground construction, it has become necessary to look forward towards it in terms of research. Though various authors have covered this, but, they are limited to only underground tanks. One of the author cover underground tunnel (RCC). Despite of this, more focus needs to be put on underground and partially underground buildings design and construction using STAAD Pro.

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