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Evolving the ESR Design using Precast Staging with Galvalume Tanks for Various Heights, Volumes and Seismic Zones to Fulfill Jal Jivan Mission Targets

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ABSTRACT

Jal Jeevan Mission is envisioned to provide safe and adequate drinking water through individual tap connections to all households in rural belts.In India's quest to fulfil this demand,one of the major specialized activity involved is to construct 'Elevated Service Reservoirs' (ESR) which throws up a challenge due to remote locations of villages where routine construction of conventional ESR is ruled out. To meet large number of ESRs at remote and spread out villages (over 1.55 lakh) in a short time span, the only possibility is to opt for Precast Staging and Galvalume Tank system. Again the requirement of varying staging height (12m to 22m), ESR volume (50KL to 500 KL based on village population) and varying terrain & Geotechnical conditions besides different Seismic Zones (mostly II, III & IV) throws up a big set of variables. The current study aims to provide a unique systematic solution to meet all such varying designs by evolving a common methodology amenable to precasting, transportation, assembly and erection at site. Accordingly, an optimized structural design & sizing pattern is worked out which meets the requirement for all such situations effectively.

INTRODUCTION

General

The conventional ESR staging designs opt for either a cylindrical shell structure or a set of columns, both requiring construction of perfect vertical shell or long column elements joined by tie beams which requires precise formwork provisions and controlled concrete mixes ad pouring at height at individual locations which is a difficult task givn the location of villages and lack of construction facilities at such remote locations. Hence there is a requirement to evolve a design which can facilitate factory construction of various elements and quick erection at site to obtain staging of various heights. Further Galvalume tanks of various capacities are again fabricated in a factory, transported in a knocked down condition, assembled at the platform level itself and thus quick erection and commissioning of the ESR is achieved.

Galvalume material has a composition of the 55% Al-Zn alloy which is more precisely 55% aluminum, 43.5% zinc and 1.5% silicon. This is a preferred choice for such installations since such tanks are durable with superior corrosion resistance, less prone to cracking, stay free from contamination, customizable in terms of sizes and appearance color, easy to paint, relatively low cost, hygienic, environment friendly and withstand extreme conditions of temperature.

Structural System

This problem is overcome by the current design in which only the RCC foundations and a foundation tie beam is made cast-in-situ and the superstructure is worked out by assembling a series of H-frames of suitable height and weight which are amenable to transportation to far flung locations. The H frames join up in a square layout in plan to make for the staging and above the assembly of H frames a top platform is created by a set of beams placed parallel at interval not exceeding 2.5m so that precast slab panels of regular sizes may be accommodated to form a standard size platform which provides for minimum 1 m wide walkway all-around the galvalume tank. The cylindrical tank is fastened at 4-6 locations with the top platform slab using anchor fasteners. Provisions for the staircase to the platform, railing all-around and holes for pipes etc are all made suitably within the platform slab itself.

The staging frame analysis is done is using ETABS software for various loading combinations of tank full & tank empty with earthquake and wind considerations stipulated in IS 875 & IS 1893. Accordingly, various elements (columns and brace beams, platform beams, PI beams etc) are designed. The support reactions are worked out for worst load combinations and the foundation design is carried out at a depth of minimum 1.5m from existing NGL. Single spread footings are chosen for locations where Nett SBC > 10T.sqm. At locations where SBC is less than or upto 10T/sqm, raft foundation is designed using SAFE software.

For the purpose of this study first we evolved a staging and tank system for 12M height, 50KL tank capacity in seismic zone-II and by assuming various column and beam sizes optimized the structure cost. Then this same exercise was carried out for other larger tank sizes and bigger staging heights and eventually standard sizes were evolved which can be chosen for village specific population (capacity) staging heightso that houses which are upto 3 storied (say about 10m height) can be served. The underlying objective behind such structural system was to cater to the widest range of villages covered under the JJM scheme.

LITERTURE REVIEW

General

For the work done so far on the subject of precasting, erection, ESR design and construction following research papers by various authors were referred to which have used a variety of analysis and design tools to address similar structures and their findings are summarized below:

Sagar Chinchghare, Prof. Rahul Hinge (2022)- In this paper the damage possibilities of elevated water tanks are considered during earthquake. Due to huge (self & water) load on their top portion and their stringent safety performance requirements critical in earthquakes, water tank must be safeguarded against failures. Various aspects which may have implications for failure such as Soil-structural interaction, fluid structure interaction, type of supports, wall flexibility, staging height, water fill conditions etc are studied in this paper. The findings dictate for precise analysis and choosing suitable locations where soil types will not be prone to differential settlement and unforeseen stresses during earthquakes.

IVHP Yasasswi & Dr. B Kesva Rao (2022)-Response of elevated storage tanks under seismic events is studied and the structural analysis modes are categorized into five Classifications-Equivalent Static Analysis, Response Spectrum Analysis, Linear Dynamic Analysis, Non-Linear Dynamic Analysis &Non-Linear Static Analysis. The findings conclude that seismic events generate displacements, and drifts which have to be adequately catered in the designand choice of material.

Ajagbe, W.O., Adedokun S. I. and Oyesile W.B (2012)- Comparative Study on the Design of Elevated Rectangular and Circular Concrete Water Tanks. This paper studies the circular versus rectangular water tanks comparison and goes on to conclude that the circular water tanks present an effective and cost optimized solution for such tanks. However, the choice of tank shape and geometry depends on the site location, condition and other requirements of the project. Furthermore, the tank height and dia should also be optimally correlated so that the hydrodynamic forces become lesser and quantities optimized. This study is very useful when a large number of tanks are to be constructed since small gains per tank will result into significant savings.

Aminu Muhammed Audu, O.B. Oloche, F.H. Tobins, I.D. Muhammad-In this paper the researcher discuss the optimal design overhead tank staging structure and it is brought out that a framing arrangement which choses square panels and cross bracings will result into suitable behavior of the tank under earthquakes, considerably limiting the displacement and drifts.

S. Vijaya Bhaskar Reddy, S. Rajashekar, Srinivas vasam P, Srinivasa Rao (2015)-Comparative Study on the Design of Square, Rectangular and Circular Concrete Water Tanks – In this paper the researchers have made a comparative analysis of various configurations viz. rectangular, Square and circular for the water storage tanks and made a stepwise correlation of the benefits of one type over the other besides a cost comparison.

Sugeng WIJANTO1 and Takim ANDRIONO (2008)- Research & Application of precasting &prestressing concrete systems in Indonesia are studied.Beam column joints & the connection systems have been discussed. It has also concluded that the construction speed was able to be increased significantly in-line with the achievement of better quality works and eco-friendlier construction projects. The use precast/prestressed concrete as structural components has been enhancing the construction quality, particularly where large modular construction projects such as housing, repeat walls etc. are required. Therefore, it is desirable that every region develops common codes and standards for this type of structural systems.

Dona Rose K J, Sreekumar M, Anumod A S (2015)- Study of Overhead Water Tanks Subjected to Dynamic Loads-in this paper the response of the elevated circular type water tanks as subjected to dynamic forces are studied. Since Overhead water tanks consist of huge water mass at the top of a slender staging which are most critical consideration for the failure of the tank during earthquakes. Tanks of various capacities with different staging height is modelled using ANSYS software. The analysis is carried out for two cases -tank full and half level condition considering the sloshing effect along with hydrostatic effect.

Santosh Rathod1, Prof. M.B.**Ishwaragol (2018)-** overhead water tank of capacity one lakh litre and a comparison is made in between the model with different staging height and with different base width and the analysis is carried out using an Staad.pro Software. Taking following thingsin considerationare water levels i.e. full/part tank level, Earthquake zones II/III/IV etc.After the completion of the analysis a comparative studyis carriedout withrespect to Bending moment, SF&Displacement variation of the columns & beams for different staging heights and base width of the water tank.

P. V. Nimbalkar, Avhad Shubham, Bahad Mayuri, Jadhav Priyanka, Shelke Shivani, TirmalSanket- Design of Circular Overhead Water Tank, Modelling and Analysis Using Staad-Pro. The theory underlying the manual analysis and design of an overhead circular water tank using the Working Stress Method (WSM) and corresponding software modeling and analysis using STAAD.PRO has been studied. It is concluded that manual WSM method available for such symmetric structures also bring out results quite in line with the advanced analysis using the software.

Prashant Attri1, Karthikeyan Murugesan(2021)-A Review Paper on Precast Concrete. This research brings out the fact that precast technology (PCC technology) accounts for about 2% of the total Indian construction industry and at present the adaptation PCC technology is limited to infrastructure projects like metro, monorail, bridges, etc. Researchers suggest that the use of PCC technology is a sustainable method to achieve high quality with lower consumption of resources such as cost and time during construction. Precast concrete is a smart way to construct any type of building safely and economically and while assuring fast construction times, high economic efficiency and excellent quality.

Kishan Desai, Maulik Kakadiya (2020)- A review paper on analysis and design of precast building using etbas. It is brought out that the adoption of more mechanization, computer aided manufacturing, and intelligent management systems will mean more precasting possibilities. Analysis and Design of Precast building system requires knowledge of construction practice as well as structural integrity. Precast Concrete Institute (PCI) provides guideline related to precast building systems element design and various connection design. PCI handbook is based on the ACI 318 codal provisions. The precast building system includes precast hollow core slab, precast beam and columns. Different configuration of precast slab, beam and columns are studied. Precast building is analyzed considering dead load, live load, seismic forces, wind forces and their combinations. For modelling and analysis of building ETABS software is used. Precast structural elements of the building are designed as per PCI and ACI specifications. The connection between slab and beam, beam and column, column and column are designed and detailed.

L. Kiruthika, s. Parthiban(2015)-Prefabricated building with precast post tensioned slab paper describes that Prestressed has internal stresses of certain magnitude applied in concrete structure so that the external loads are counteracted to certain degree. In Reinforced concrete, the prestress is commonly introduced by tensioning steel reinforcement. Reinforced concrete is a combination of plain concrete and steel, which forms a composite material. In precast, the reinforcement may be provided as conventional method or by providing prestressed steel and hence they have more strength compared to cast in situ. High quality architectural products are produced with greater accuracy in prefabricated structure. It describes the various method of construction of members and the analysis and design of a precast prestressed concrete commercial building with the design of post tensioned concrete flat slab and also the comparison between them and explaining the usage and advantages of prefabricated structure over the cast in situ concrete used in conventional structure.

Rakesh Khare, MM Maniyar, Sr Uma (2011)- An overview on Seismic performance and design of precast concrete building structures. Seismic performance and behavior of precast concrete structures which were not designed and detailed as per existing provisions in relevant standards was very poor during past earthquakes while the buildings constructed and designed incorporating seismic design concepts performed remarkably well. A brief review of seismic performance and design of precast concrete systems is presented to seek for the ways to improve and develop construction of precast concrete structures in India. This paper brings together the historical perspective on the performance of precast concrete structures so that lessons can be learnt to avoid the poor performance of these systems. An extensive literature on experimental studies has been also reported in this paper to demonstrate the improved seismic performance of precast concrete systems. Further, a review and comparison of International code provisions on the design and construction of precast concrete systems is presented to help in developing the provisions and practice of these systems in Indian perspective. Identification of areas that need revision or attention in the current IS Code provisions are attempted in the light of International practice.

METHODOLOGY

General-

A suitable staging frame of 4 columns 12m height with platform at top is conceived with arrangement & geometry amenable to precasting.This is done by piecing together, Series of H Frames Comprising of 2 columns & Brace beam in between. The Tank size being 4.10m Dia& 4.25m Overall height, with water height of 3.787m is taken as per vendor details.The platform size of 6.1mx6.1m is chosen so that there is a movement cum maintenance space of minimum 1000mm all around the steel tank. Grade of Conc. M40 for all Precast Elements & M30 for Cast-in-situ(Foundations Tie Beam & UptoPedestaltop) , Reinforcement. Steel Grade Fe 500, Cover to reinfo. etc is taken as per standard practice in IS:456.

Steps involved in the Modelling & Analysis

1. For the chosen sizes of preliminary data, weight calculations are carried out wherein: Column 325x325, Brace Beam 230x300, Platform Beam 250x450/400, Pie Beam 250x525.
2. LL on Platform level may be ignored during EQ condition, however it is considered on entire platform & tank area in vertical load case. Water load is considered as DL (permanently in place).
3. For Seismic analysis, freeboard is not included in the depth of water. As such as 300mm FB is considered in weight calculations during other load combinations, so that the platform beams will cater to that excess FB load also.
4. The CG of steel tank with water is assumed conservatively at 1.9m height from platform top and parameters of spring mass model are defined as per provisions of IS1893 part-2:2014
5. Wind forces are computed on the various elements (Beams, Columns, Braces & the Tank) in line with IS 875 Part-03:2015 provisions. After applying these forces, the frame is analyzed&Column & braces designed as well as support reactions obtained which are compared with Earthquake case forces later &more severe of the two adopted for design of various elements including the brace beams, columns and foundations. It is seen that in column design wind governs on windward side while EQ governs on leeward side column. For Foundation, however wind governs.
6. The load combinations have been appropriately chosen for Limit State of Serviceability& Limit State of Collapse in line with codal provisions (IS:875 part-5 & IS:1893 part-2) and the same are covered in the ETABS Report.

Description of Load Combination	Load Cases under Consideration					No. of Combinations	Remarks
	DL (Dead Load as self weight of Staging+ Platform & PI Beam+ Platform Slab)	(LL) Live Load (On Platform & Water Weight in Steel tank)	Wind Load (WL)	Earthquake Load (X)	Earthquake Load (Y)		
1.5(DL+LL)	1.5	1.5				1	
1.5(DL+LL+/-EQ x/y)	1.5	1.5		1.5	0	2	For EQ in + & - Direns
				0	1.5	2	
1.5(DL+LL+/-WL x/y)	1.5	1.5		1.5	0	2	For Wind in + & - Direns
				0	1.5	2	
0.9DL+/-1.4 Wind	0.9		1.4			4	Considering + & - directions
0.9DL+/- 1.4EQ	0.9			1.4		4	
1.5(DL+LL+/-EQ Diagonal direction)	1.5	1.5		1.06	1.06	2	
1.5(DL+LL+/-WL Diagonal direction)	1.5	1.5	1.06 (in X & Y both)		1.06	2	
1.5(DL+LL+/-EQ x+0.3EQy)	1.5	1.5		1.5	0.45	2	
1.5(DL+LL+/-EQ y+/-0.3EQx)	1.5	1.5		0.45	1.5	2	
					TOTAL	25	

7. Design is done for above listed combinations, however deflections are checked for service loads.
8. Lateral stiffness of spring (force required to be applied at platform level to get a unit deflection) is determined using the ETABS analysis by applying 10KN force on the frame. However, since the Unit load should act at the CG of the tank level, the same is transferred to the platform top level as a shear and the resulting moment (for 1.9m height difference) between tank CG and platform top.
9. Time period is calculated first for impulsive mode based on which the Design Horizontal seismic coeff is worked out for Impulsive mode.

10. Similarly, the Time period is calculated for convective mode based on which the Design Horizontal seismic coeff is worked out for Convective mode.
11. Consequently, base shear contributions for both modes are computed and a vector sum is taken as the 'Total Base Shear' in line with codal provisions.
12. A similar analysis is carried out for the 'Tank Empty condition' where only the 'Impulsive mode' shall be applicable.
13. Thus the base shear & base moment is assessed for both Tank Full & Tank Empty cases and the higher value is used for design.
14. The Platform cum staging frame is analyzed for the calculated base shear (for both EQ case and wind case along with suitable DL & LL acting on platform). Post analysis in ETABS the staging beams are designed directly from ETABS. Similarly, column design is also taken from ETABS software. However, the Platform level beams are designed conservatively (using software as well as manually and severe of the two considered) to reflect for increased load due to water in FB zone as well as LL coming over entire platform and tank plan area as well.
15. Crack width for all beams (staging beams & Platform beams) is checked & restricted at 0.2 mm
16. .A pedestal of size 525x525 is provided below the column up to -0.500m. A tie beam is provided (size 325x450) at this level of -0.500. The foundation design is done for the loads and moments thus transferred to the bottom of foundation level.
17. Foundation is designed as independent isolated footing keeping settlement at 40mm(a net allowable SBC as per soil report made available by client. Net SBC Range = 8 ton/sqm to Max 50 t/sqrm at different locations.
18. A prefabricated steel staircase shall be used (max 0.9 m wide) to climb to the top of the platform level. Suitable treads & risers are chosen and steps formed using 5mm thk chequered plate spanning between two stringer beams ISMC 100/150. Suitable railing using pipe section (NB32 medium for top rail & NB25 med for knee rail & toe rail may be used with posts at about 1.5m spacing suitably placed on stringers. First three straightflights spanning between the opposite ends of the staging and the 4th flight made at normal to these with a cutout provision within the Platform Slab suitably.

PROBLEM IDENTIFICATION

General

In this special type of design of the ESR staging it may be observed that since individual modules of typical H-frames are made the location of brace beams shall not be at similar levels on all 4 sides. However, the beams shall be at matching levels on opposite faces. This is quite unlike the conventional designs. Further the platform beams are simply supported on top of the staging frame and they are accordingly modelled in ETABS. In precast structures the placement of beams and location of pin supports is to be carefully identified and modelled in line with the actual conditions arising. Furthermore, a cutout in the platform slab is made to accommodate the staircase leading from Ground to platform to attend to the tank maintenance etc.

Concerns Affecting Designs:

1. Over & above the regular ETABS analysis of the Unit frame and the regular frame, in order to get the most realistic estimate of the forces arising during lateral (wind & EQ cases), a P-Delta analysis is also carried out and the resulting secondary forces (moments & shears) captured carefully.
2. A major concern in Precast structures is the assembly of elements and connections. Since a system of H- frames is used, the connections of beam to column are automatically taken care of. However,connection of column elements with each other is worked out using groutech couplers. They ensure perfect joint formation with effective connection and they have been suitably conceived at column mid heights where the BM is likely to be near zero. However, the couplers are adopted for the largest bar dia only so that the continuity of the column at connection location is well maintained and the section is equally efficient in capacity as at maximum moment locations

RESULTS & DISCUSSION

The entire work of analysis &design of precast structure is centered around the corresponding execution aspects and it must be ensured that the design intent is actualized in construction execution as will such as:

1. Ease of manufacturing
2. Modular concepts
3. Precision of construction
4. Sizes of elements to be kept amenable to transportation
5. Connection design

6. Storage, stacking, sequencing of various elements at siteviz a viz the space constraints at site.
7. Handling of various precast units in correct sequence to get the assembly right
8. Erection aspects, crane capacity, movement pattern of cranes etc.
9. Working of multiple agencies at site so that the whole project of ESR along with other aspects like pipeline network, pump-house etc. is all accomplished together.

CONCLUSION

From structural aspects alone following were the findings:

1. The system of H frames behaves extremely well since the effective length of columns is controlled in both directions thus resulting in optimum sized columns. In our case a column size of 400x400mm was selected and this attracted only nominal reinforcement (4T16+4T12)
2. The connection of the two H frames together is to be carefully planned keeping in mind the latest couplers of Dexa type which permit junction of eight bars at same location.
3. The deflections in unit frame and the resulting base shear computations are a key to achieving the right dimensions for elements such as column, brace beam (230x300) and the platform beams above.
4. The connection detailing of the top slab panels is to be meticulously worked out with the platform beams so that the platform top is in perfect level and the galvalume tank along with accessories is planned properly.

From Construction Aspects following were the findings:

The problem of design does not end at the drawings stage only and it is intricately linked with the work of execution which entails a lot of planning and coordination of activities of procurement of materials to production of elements in yard to transport & execution of assembly and erection activities at site. While foundation work (CIS) is in progress, also in parallel the components are manufactured in precasting yard, and they shall be transported to works and erected and assembled in predefined sequence with all safety and quality measures in place. The bought out tank (steel) shall be anchored onto the top platform using typical details standardized by the manufacturer. Similarly, the prefabricated steel staircase is mounted on the suitably placed steel beams (to be fixed with HILTI anchors into columns). The entire work of execution including the last painting details is carried out to the quality & safety norms defined in the Quality manual (which forms an integral part of the Construction process) in the committed time frame.

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