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Design of Jackwell and Pumphouse for Lift Irrigation System

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Abstract - *Irrigation infrastructure is a critical requirement for agricultural sustainability in drought-prone regions where conventional gravity flow is ineffective. The present study focuses on the structural planning, analysis, and design of the head works components for the Bordi Nalla Lift Irrigation Scheme in Amravati, Maharashtra, designed to serve 3,161 hectares of agricultural land. Major structural components, including the intake structure, circular jack well, and a multi-level RCC pump house, were investigated to ensure safety under severe hydraulic, machinery, and seismic loading. Structural analysis was performed using STAAD.Pro software for 3D framed components and established engineering principles for hydraulic structures in accordance with IS 456:2000, IS 3370, and IS 1893:2016. The results indicate that all designed components are structurally stable, with the jack well exhibiting a factor of safety against flotation of 1.56, which safely exceeds the required 1.2 limit. Comprehensive stability checks for overturning, sliding, and soil bearing capacity confirmed the adequacy of the proposed structural configuration. The study validates that this integrated design approach provides a reliable, durable, and economical solution for implementing sustainable irrigation infrastructure in plateau terrains.*

Key Words: Lift Irrigation Scheme, Structural Design, STAAD.Pro, Intake Structure, Jack Well, Pump House, Water Retaining Structure, Irrigation Infrastructure

1. INTRODUCTION

1.1 General Overview

Water scarcity and irregular rainfall in regions like Vidarbha significantly impact agricultural productivity and the national economy. Conventional gravity-based irrigation systems are often unable to serve cultivable lands situated at higher elevations than reservoir water levels. Therefore, the development of reliable Lift Irrigation Schemes (LIS) has become essential for ensuring agricultural sustainability and food security in drought-prone regions.

The mechanical lifting of water using pumping systems and pressurized pipelines has emerged as a promising engineering solution for providing assured irrigation to plateau terrains. The LIS method is based on the mechanical conveyance of water from a lower source to higher elevation fields, where hydraulic structures such as intake works, jack wells, and pump houses must maintain structural integrity under severe hydrostatic forces, earth pressure, and machinery loads.

Several researchers have successfully applied structural design principles for isolated hydraulic components like water tanks and intake works. However, limited studies are available regarding the integrated structural design of complete lift irrigation head works involving intake structures, circular jack wells, and multi-level pump houses as a combined system. Therefore, the present investigation focuses on the structural planning, analysis, and design of the major head works components for the Bordi Nalla Lift Irrigation Scheme in Amravati, Maharashtra.

The structural models developed for the 3D framed pump house and other water-retaining components were processed using STAAD.Pro software and established engineering methodologies for graphical and stress analysis. The effectiveness of the proposed structural configuration was validated using Indian Standard codes such as IS 456:2000, IS 3370, and IS 1893:2016, ensuring the safety of the infrastructure against overturning, sliding, and flotation.

1.2 Lift Irrigation System

A Lift Irrigation System (LIS) is used to convey water from lower elevations to higher agricultural areas using mechanical pumping instead of gravity flow. Such systems are highly suitable for Maharashtra due to its uneven terrain and availability of reservoirs. Lift irrigation improves water-use efficiency, reduces conveyance losses, and supports assured irrigation and higher agricultural productivity.

The Bordi Nalla Medium Project consists of major components including the intake structure, jack well, and pump house. The intake structure regulates and directs water from the reservoir while preventing the entry of debris and sediments. The jack well acts as a sump for temporary storage and provides adequate submergence for pump operation while resisting hydrostatic and uplift pressures.

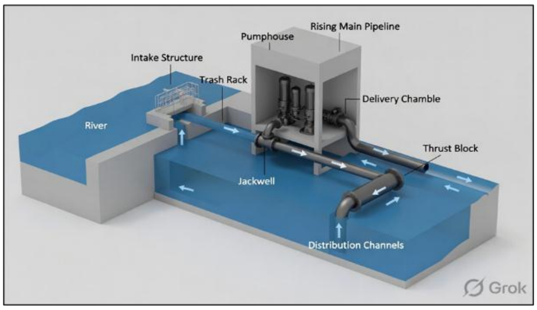


Fig -1: Lift Irrigation System

The pump house is a multi-level RCC framed structure housing pumps, valves, control systems, and a 7.5 T EOT crane. It was analysed as a three-dimensional space frame using STAAD.Pro considering dead loads, live loads, crane loads, and seismic forces. The overall design ensures structural safety, stability, durability, and efficient operation of the lift irrigation system

1.3 Objectives of the Study

The effectiveness of a lift irrigation scheme relies on the safety, efficiency, and durability of components like the intake structure and pump house, which endure significant stresses. An analytical approach is essential for stability and reduced maintenance. Proper design enables cost-effective construction and a reliable water supply for agricultural areas not served by traditional methods. This study focuses on assessing and designing the structural components of the Bordi Nalla Lift Irrigation Scheme in accordance with Indian Standard codes.

The objectives of the present investigation are:

1. To study project-specific hydraulic parameters and establish durability requirements for moderate exposure conditions as per IS 456:2000.
2. To analyse and design the circular RCC jack well considering circumferential hoop tension, hydrostatic pressure, and uplift pressure acting on the raft foundation in accordance with IS 3370 provisions.
3. To evaluate the flotation stability and bearing pressure behaviour of the jack well under submerged and operational loading conditions.
4. To develop a three-dimensional RCC beam-column frame model of the pump house using STAAD.Pro software for analysis under dead load, live load, crane load, and seismic loading conditions.
5. To analyse critical pump house components such as beams, slabs, staircase elements, corbels, and crane-supporting members for bending, shear, deflection, and serviceability requirements.
6. To verify the overall structural safety, stability, and serviceability performance of the jack well and pump house RCC frame using relevant Indian Standard code provisions.

2. METHODOLOGY

2.1 General

The structural safety, serviceability, and durability of hydraulic structures are essential for the reliable functioning of Lift Irrigation Schemes in drought-prone regions. For this study, the head works components of the Lift Irrigation Scheme associated with the Bordi Nalla Medium Project were analysed and designed in accordance with relevant Indian Standard codes. The methodology includes detailed structural planning, load estimation, stability analysis, and design of the intake structure, RCC approach box conduit, circular jack well, multi-level RCC framed pump house, delivery chamber, and thrust blocks. The pump house was modelled and analysed as a three-dimensional frame using STAAD.Pro software, while the water-retaining structures were designed using the Working Stress Method to ensure water tightness and crack control.

2.2 Data Collection and Governing Parameters

The design and analysis of the structural components are primarily governed by a set of hydraulic, geometric, and operational parameters. These parameters form the basis for determining loading conditions, structural dimensions, and design criteria. The values of these governing parameters are obtained from project data and approved design reports, and they are considered throughout the analysis to ensure consistency and accuracy in design.

Table -1: Governing Parameters

Sr. No.	Features	Proposed
1	Design Discharge	1.77 m^3/s
2	M.D.D. L	340.995 m
3	F.R.L	351.000 m
4	A.H.F.L	352.000 m
5	Ground level	353.000 m
6	Sump bottom level	337.500 m
7	Valve Floor Level	353.500 m
8	Pump Operating Level	344.160 m
9	FSL in D.C.	371.500 m
10	Length of Rising Main	2075 m
11	Dia. of Rising Main	1050 mm
12	Thickness of rising main	7 mm
13	Velocity in Rising Main	2.038 m/s
14	Static Head for rising main	17.20 m
15	Friction head for rising main	6.52 m
16	Static Head for pump	27.35 m
17	Friction head for pump	7.80 m
18	Efficiency of pump	85 %
19	Total H. P provided	978 HP
20	No. of pumps	3 No.
21	H. P per pump	326 HP
22	Type of Pump	Submersible

2.3 Structural Modelling and Analysis Method

The structural modelling and analysis of the jack well and pump house of the Bordi Nalla Lift Irrigation Scheme were carried out using both manual design procedures and computer-aided structural analysis techniques in accordance with relevant Indian Standard code provisions. The circular RCC jack well was analysed considering circumferential pressure developed due to stored water and hydrostatic action on the wall surface. The raft foundation of the jack well was analysed for upward pressure acting from the bottom of the structure to evaluate uplift effects and foundation stability. The design of the jack well components was performed using the Working Stress Method in accordance with IS 3370 provisions for liquid retaining structures and IS 456:2000 provisions for reinforced concrete design. The RCC detailing of the wall and raft sections was finalized based on the governing stresses and reinforcement requirements.

The pump house superstructure was modelled as a three-dimensional RCC beam-column frame using STAAD.Pro software. The analytical model included RCC columns, beams, slabs, staircase elements, corbels, gantry beam supports, and crane-supporting structural members. Structural loading considered in the analysis included self-weight, live load, machinery load, crane wheel load, and earthquake load combinations. The EOT crane loading was analysed under different wheel positions to determine critical bending moment and shear force conditions in the corbel beams and supporting members. Material properties, support conditions, member dimensions, and load combinations were assigned in accordance with IS 456:2000, IS 875, and IS 1893 provisions.

The RCC framed components of the pump house, including beams, slabs, staircase waist slab, corbels, and gantry-supporting members, were analysed and designed using the Limit State Method. Manual calculations, Excel-based design sheets, and STAAD.Pro analysis outputs were used for evaluating bending moments, shear forces, axial forces, reinforcement requirements, deflection criteria, and serviceability conditions. Structural safety checks for shear strength, deflection limits, reinforcement detailing, and durability requirements under moderate exposure conditions were performed before finalizing the structural configuration and reinforcement detailing for practical implementation.

2.4 Load Combinations and Performance Checks

The pump house and associated RCC framed components of the Bordi Nalla Lift Irrigation Scheme were analysed for both Ultimate Limit State (ULS) and Serviceability Limit State (SLS) conditions in accordance with IS 456:2000 provisions. The structural analysis considered the combined effects of dead load, live load, crane load, machinery load, and earthquake load to evaluate the safety and serviceability performance of the structure under critical operating conditions.

A. Ultimate Limit State (ULS) – For structural strength verification (bending, shear, axial forces):

- 1.5 DL ± 1.5 EQX/EQZ
- 0.9 DL ± 1.5 EQX/EQZ
- 1.5 DL + 1.5 LL + 1.05 C.LEFT/RIGHT
- 1.2 DL + 1.2 LL + 1.05 C.LEFT/RIGHT ± 0.6 EQX/EQZ
- 1.2 DL + 1.2 LL + 0.53 C.LEFT/RIGHT ± 1.2 EQX/EQZ

B. Serviceability Limit State (SLS) – For deflection, crack control, and functional performance:

- DL ± EQX/EQZ
- DL + LL + C.LEFT/RIGHT
- DL + 0.8 LL + 0.8 C.LEFT/RIGHT ± 0.8 EQX/EQZ
- DL ± EQX/EQZ + C.LEFT/RIGHT

(DL = Dead Load, LL = Live Load, CL = Crane Load, EQ = Earthquake Load)

Detailed performance verification was performed under critical operating conditions. The checks performed were buoyancy and flotation analysis of the circular jack well when empty, soil bearing capacity assessment for the foundation under different loading conditions and stability evaluation of the intake head wall against overturning and sliding. Deflection and shear serviceability checks were carried out for RCC slabs at valve floor, control floor and roof levels. The staircase waist slab was analyzed as a one-way continuous slab for deflection and shear stress.

Table -2: Load Calculations for STAAD Input

Floor Level	DL + FF (kN/m^2)	LL (kN/m^2)	Brick Wall Load (kN/m)
Roof	5.00	0.75	-
EOT Crane Beam	5.00	1.5 (Walkway) 3.0 (Lintel)	13.80
Control panel	5.00	5.00	12.88-14.95
Valve Floor	6.25	7.50	12.65

Flexure, shear friction and tension reinforcement of corbel and gantry beams were evaluated under crane wheel loads. Further, the crack control was checked for water retaining structures like jack well and delivery chamber using Working Stress Method.

3. RESULTS AND DISCUSSION

The structural analysis and design results for the major headworks of the Bordi Nalla Lift Irrigation Scheme indicate that all components satisfy the rigorous safety and serviceability criteria established by Indian Standard codes. The following sections evaluate the performance of critical structures under varied hydraulic and geotechnical loading conditions.

3.1 Structural Stability of the Jack Well

The structural stability of the RCC jack well was evaluated under two critical loading conditions to assess flotation safety and foundation performance. The analysis was carried out considering hydrostatic pressure, self-weight of the structure, live load, and uplift pressure acting on the raft foundation. The jack well was analysed as a liquid-retaining structure using the Working Stress Method in accordance with IS 3370 provisions.

Two governing cases were considered during the stability analysis. Case-A represented the submerged external condition with the jack well empty, which is the most critical condition for uplift and flotation. Case-B represented the operational condition with water retained inside the jack well, which governs the bearing pressure on the foundation.

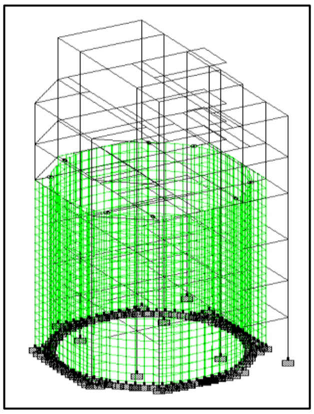
Table -3: Buoyancy and SBC check

Description	Case-A: Submerged Outside	Case-B: Water Inside
Design Dead Load	20,224 kN	-
Live Load	1,118 kN	-
Water Load	-	15,260 kN
Total Load on Raft	21,342 kN	36,602 kN
Buoyancy Force	39,476 kN	Not Governing
Factor of Safety	1.56 (>1.2 -Safe)	-
Bearing Pressure	7.90 T/m²	13.50 T/m²
SBC	15.00 T/m²	15.00 T/m²
Result	Safe	Safe

The results demonstrate that the proposed RCC jack well configuration is structurally stable under both submerged and operational loading conditions. The raft foundation was found adequate against uplift pressure, flotation, and excessive soil pressure, thereby ensuring safe and durable performance of the structure under critical hydraulic conditions.

3.2 Performance of the Pump House RCC Frame

The structural performance of the pump house was evaluated using a three-dimensional RCC beam-column frame model developed in STAAD.Pro software. The model was analysed using M25 grade concrete and Fe500 reinforcement considering dead load, live load, crane load, soil pressure, and seismic forces corresponding to Seismic Zone II.



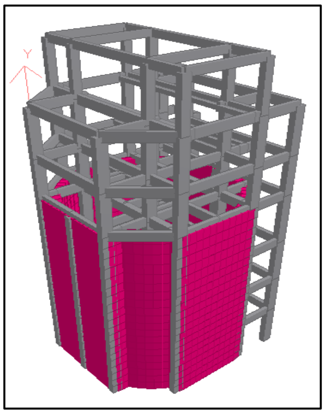


Fig -2: 3D Model **Fig -3:** 3D Rendering View

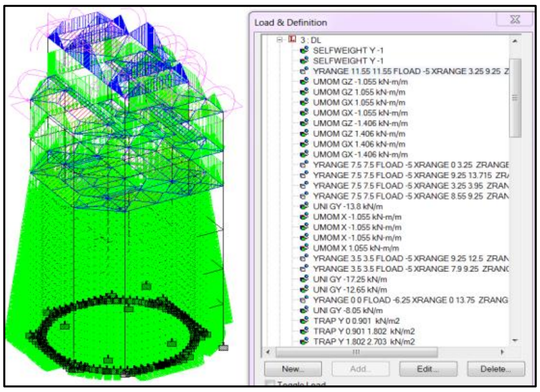


Fig -4: Dead Load

Both Ultimate Limit State (ULS) and Serviceability Limit State (SLS) load combinations were considered to evaluate bending moments, shear forces, axial forces, and support reactions in the structural members. Special attention was given to the analysis of RCC corbel beams subjected to 7.5 T EOT crane wheel loads under different wheel placement conditions to determine critical stress behaviour

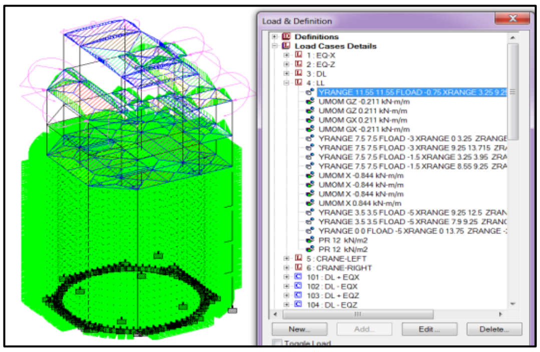


Fig -5: Live Load

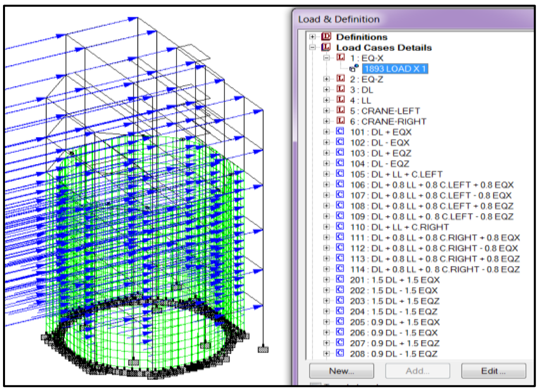


Fig -6: Earthquake Loading in X-Direction

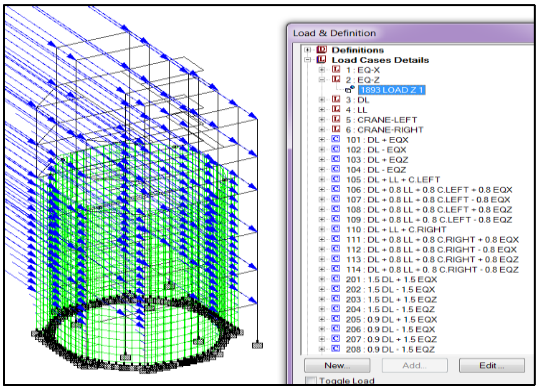


Fig -7: Earthquake Loading in Z-Direction

The analysis results indicated that the pump house RCC frame satisfied the required strength and serviceability criteria under all governing load combinations. Beams, slabs, staircase elements, and corbel members were found safe against flexure, shear, and deflection requirements as per IS 456:2000 provisions. Manual design checks using Excel sheets were also carried out for critical components to validate the STAAD.Pro analysis results.

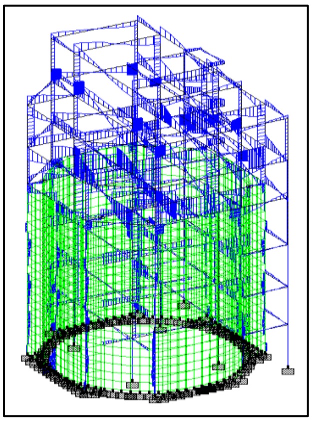


Fig -8: Shear Force Diagram

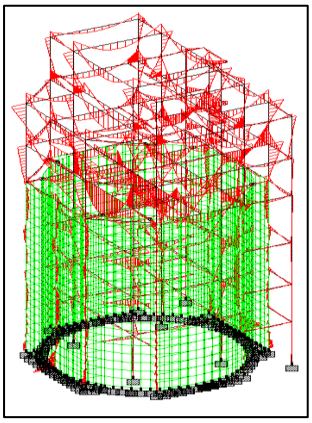


Fig -9: Bending Moment Diagram

Overall, the analytical and manual verification confirmed the structural adequacy and stability of the proposed RCC pump house system under combined operational and seismic loading conditions.

4. CONCLUSIONS

This study concludes that the structural planning, analysis, and design for the major headworks of the Bordi Nalla Lift Irrigation Scheme provide a safe, durable, and code-compliant infrastructure. The design ensures hydraulic efficiency and structural integrity for all components by adhering to rigorous safety standards for water-retaining and superstructure elements.

The key findings are summarized below:

1. The analysis and design results showed that the structural components satisfied strength, shear, deflection, and serviceability requirements as per relevant IS code provisions, and the proposed configuration was found safe for implementation.
2. The circular RCC jack well satisfied the requirements of IS 3370 for liquid-retaining structures and provided adequate resistance against hydrostatic and circumferential stresses.
3. The STAAD.Pro analysis of the pump house RCC frame demonstrated satisfactory structural behaviour under combined dead load, live load, crane load, and seismic load combinations.
4. Critical structural components including slabs, beams, staircase waist slab, and corbel beams were found safe against flexure, shear, and deflection requirements as per IS 456:2000 provisions.
5. Manual calculations and Excel-based verification showed good agreement with STAAD.Pro analysis results, confirming the reliability of the adopted modelling and design methodology.
6. The proposed RCC jack well and pump house configuration was found structurally stable, serviceable, and suitable for practical implementation in the lift irrigation scheme.

This integrated design approach is recommended as a reliable and efficient configuration for medium irrigation projects. While manual verifications ensure the accuracy of individual components, 3D STAAD.pro modelling remains essential for validating the complex interaction of the pump house frame under operational and environmental forces.

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