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Analysis of the Approach to Safe Technical Lifting of Large Crane Machinery

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Abstract: The continuous expansion of large-scale construction projects has driven a surge in demand for heavy lifting operations. Complex lifting operations come with significant safety risks. Multiple serious accidents have exposed the inadequacies of traditional experience-based management in facing extreme working conditions. Safe lifting technology embodies systematic engineering attributes, with its core encompassing precise mechanical calculations, meticulous scheme design, dynamic environmental adaptation, and efficient collaboration among multiple parties. There is a gap between theory and practice in existing technology and management models. The industry urgently needs to integrate advanced technology and scientific management concepts to build an intrinsic safety system that covers the entire lifting process. Exploring systematic safe lifting technology ideas has profound practical value in curbing major accidents and safeguarding the development of the industry.

1. Introduction

The safe lifting of large-scale lifting machinery ensures the safe and efficient advancement of national major engineering construction. Its theoretical foundation is built upon the analysis of complex structural mechanical properties, identification of safety elements in lifting processes, coupling mechanism of environmental variables, and the logic of whole-process safety control. The depth of theoretical research and the precision of practical application directly affect the safety level of on-site operations. The current technical system faces severe challenges in extreme load prediction, dynamic environmental response, and human-machine collaborative reliability. Breaking through bottlenecks requires going beyond local optimization and adopting systematic solutions. Deeply analyzing the theoretical foundation of safe lifting, accurately diagnosing practical bottlenecks, and planning an integrated implementation path accordingly have become core propositions for enhancing the intrinsic safety capabilities of the industry.

2. Theoretical basis for safe lifting of large lifting machinery

2.1. Analysis of mechanical characteristics of lifting machinery

Every extension of the steel giant arm of large lifting machinery affects the delicate mechanical balance. The strength and rigidity of the equipment's own metal structure form the cornerstone of safety, and the distribution of composite stress it bears directly determines the equipment's resistance to deformation and stability limit during lifting. The weight, geometric shape, and center of gravity of the lifting object profoundly affect the tension distribution of the steel wire rope and the stress state of the lifting hook. Any calculation deviation or perception error can trigger dangerous swaying or even overturning. The on-site wind acts like an invisible shifter, and the lateral load it exerts continuously tests the anti-rollover capability and foundation anchoring reliability of the lifting machinery. A soft or uneven foundation is like a buried hazard, and minor settlement or local instability can instantly destroy the carefully calculated support balance. Understanding and precisely controlling these visible and invisible force interactions is an indispensable prerequisite for the safe landing of large lifting operations. It requires technicians to transform cold formulas into keen insights into the dynamic behavior of the steel giant.

2.2. Core safety elements of lifting process

The operator verifies the weight parameters of the lifting equipment to determine the load capacity of the crane, checks the effectiveness of the hook safety device to eliminate the risk of unhooking, and counts the number and length of slings to match the binding requirements of the components. The project leader confirms the setting of warning lines in the operation area to prevent unauthorized personnel from entering, directs the signal worker to establish a communication intercom system between the tower crane and ground personnel, and reviews the flatness of the subgrade box beneath the bearing plate of the crawler crane's outrigger. When the meteorological information receiving terminal indicates a sudden change in wind force that triggers the equipment warning threshold, the technical team immediately suspends the suspension operation to investigate the swing amplitude of the components. The safety supervisor locks the slewing mechanism to prevent the boom from being offset by crosswinds. The guy rope group adjusts the air balance of steel components based on the distribution state of counterweights, and the lifting engineer monitors the winch mechanism's brake throughout the process to ensure continuous and effective engagement. During the flange docking process, positioning pins are used to control the precise alignment and descent of the pipe column. The hydraulic lifting system applies graded loading pressure to ensure the synchronous lifting of large trusses, and the balance beam design disperses local stress at multiple lifting points to avoid structural deformation. If the foundation settlement monitoring data is abnormal, the counterweight adjustment plan is immediately initiated. These specific operational actions constitute the core control chain to prevent lifting overturning, and on-site personnel implement the physical execution of each link to form a safety closed loop [1].

2.3. The correlation between environmental factors and safety

The on-site environmental monitoring system collects real-time data from wind speed sensors to trigger lifting limit warnings. The geological exploration team scans the underground pipeline distribution map to mark the coordinates of the crawler crane exclusion zone. The humidity sensing device captures condensation trends to identify risk periods for steel cable slippage. Residents in the surrounding community report interference from the rotating light spot of the tower crane, leading to an agreement to shut down during non-operating hours. The municipal department verifies the distance data of high-voltage lines to establish limits on the boom's turning angle. In the event of sudden heavy rain and water accumulation flooding the leg monitoring points, the automatic leveling system is activated. Concrete pump trucks in narrow areas force cranes to reduce their turning radius, and vibration waves from piling at adjacent construction sites are transmitted to the counterweight area, causing abnormal readings on the level meter. Changes in ground pressure on the track shoes in the ramp area drive multiple sets of jacks to dynamically compensate for pressure. The relational model shown in Figure 1 reveals the penetration paths of meteorological, geographical, and social variables on the lifting safety net.

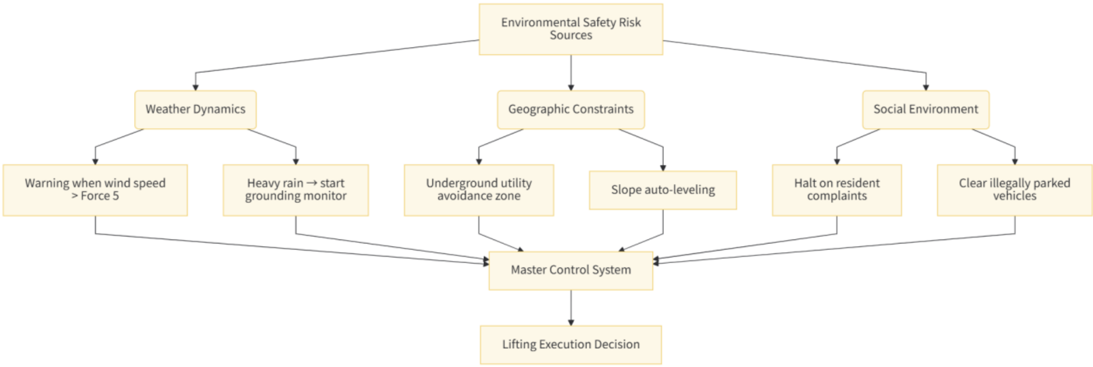

Figure 1 Relational model

3. The key safety bottleneck in current large-scale lifting operations

3.1. Deviation in judging load characteristics under complex working conditions

In extensive lifting operations, deviation in judging load characteristics under multifarious working conditions constitutes a considerable hidden danger that may lead to safety accidents. Operators often underestimate the risks of dynamic loads, and inertial forces generated through the crane boom's swinging or sudden lift may severely exceed their projected calculations. The evaluation of wind effects is not an accurate process for some construction teams, and provided that sudden gusts of wind at high altitudes occur, this may lead to considerable sway of the lifted objects, when in some circumstances, the actual forces may outrank theoretical values significantly. Due to some special components being irregular in shape or offsetting their center of gravity, personnel at the site often do not correct the lifting position of the point of lifting but continue to fail in controlling the load, additionally causing stress loading to be uneven on the multiple steel wire ropes for these instances. Variations in ground support conditions may also disrupt their load judgements. Using soft engineered foundations, may lead to unavoidable settlement, during the lift, and leads the legs of the crane to extreme variation in stress point imbalances.

3.2. The disconnection between the lifting plan and the actual execution

The lifting parameter table compiled by the design team based on ideal operating conditions faced practical challenges during the equipment transfer phase. The minimum safe angle of 10 centimeters for pipe racks set by the design team was compressed to less than 6 centimeters due to the narrow operation area. The periodic verification date specified in the torque limiter calibration certificate was often interrupted by the rush-work schedule, and the rated lifting weight data of the crawler crane failed to be revised in time, resulting in outdated steel plate thickness coefficients. A short section of high-strength bolts in the toolkit forced the installer to use substitutes to barely fix the tower base connecting plate. The planned dedicated lifting beam was modified on site into a simple I-beam crossbar, increasing the risk of instability. When the operators discovered that the actual spacing of the main reinforcement at the top of the tower had deviated from the reserved hole position, it had already been lifted halfway into the air, and the actual thickness of the counterweight block at the end of the tower crane's balance arm exceeded the maximum allowable counterweight range specified in the plan. Local pipelines in the underground pipeline gallery exploration map that had not been updated forced the temporary support area of the crawler plate to deviate from the stress calculation position, and the preset angle of the monitoring probe was unable to capture the sudden leakage phenomenon of the turntable's rotary hydraulic motor. The wind rope anchor points marked on the plan drawings were completely covered by newly poured structural columns, and the additional wind load area of the newly added signal platform was omitted during the calculation of lifting torque [2].

3.3. Potential failure of key safety devices

The equipment maintenance team neglected the signal offset caused by rusted contacts of the tower crane's amplitude limiter during routine inspections. The maintenance team's logbook did not update the cumulative wear thickness data of the main winch brake pads beyond the limit. The built-in wind speed alarm module of the device monitor suffered from dust intrusion, blocking the wind cup's rotating bearing. The high-temperature exposure of the device monitor's LCD panel caused failure to mask the abnormal vibration value of the luffing overspeed warning encoder. When the operator switched to the grab mode, they discovered that the positioning pin of the clutch lever was missing, resulting in excessive handle play. The operator encountered a black screen on the torque limiter during nighttime operations and still forcibly lifted concrete prefabricated parts beyond the approved load. The seasonal temperature difference caused deformation of the sealing ring of the balance valve hydraulic lock, inducing the boom's downward sliding to exceed the safety threshold. The height limiter's contact rod suffered from intermittent short circuits in electronic components due to the impact of a typhoon and humid environment. The bolt of the anti-skipping slot guard for the lifting wire rope became loose and deformed, increasing the probability of the rope strands extruding out of the slot. The gear lubricant leakage of the slewing mechanism contaminated the amplitude limit switch contacts, weakening the power-off response sensitivity. The pressure sensor of the outrigger cylinder was wrapped and hardened by cement slurry, losing its verticality monitoring accuracy. The writing on the counterweight indicator label fell off, confusing the actual counterweight block and reporting a missing quantity. The spring of the main hook's over-roll buffer device fatigued and fractured, eliminating the last fall protection function. The circuit of the mobile alarm was punctured by steel bars, causing the insulation layer to break, leading to the interruption of emergency avoidance signal transmission.

3.4. Defects in multi-trade coordination and command system

The logistical and management elements of lifting construction practices have been magnified to a level of complexity in current large-scale lifting operations that introduces frequent risk and hazard events. Consecutive work types and the limitations associated with the command system to mitigate safe and effective construction proceed to present significant issues that result in chaos. For example, many lifting commanders are overwhelmed by distorted signals; due to the inordinate time-lag that exists between ground signal persons to high-altitude drivers, signals may have intended interpretations misleading signal receivers in chaotic circumstances (e.g., gesture signals if units were elevated lift and radio messages are being transmitted at the same time). In some situations, operation teams will subscribe to separate command standards: workers with different work types have independent working habits leading to an inability for crane drivers to quickly interpret the intended action of signals communicated to them. To add to these management stresses, the introduction of the chaotic area surrounding operations multiplies risks. For example, if civil workers and lifting labourers were both working at the same time, the operating action of each group was less than structured, introduced risk through this less than 100% coordinated phase of work; lastly, during this phase of work, the crane operator slowed lift-up swinging units posed risk to below ground workers. Quite often in previous projects, we would run into the problem of too many command levels (one high-profile project we undertook had a high number commanded by about three different levels of contractors), ultimately, the relationship between the general contractor and the subcontractors transmitting instruction was too long, so key operational instruction loss now put us in a difficult position to remember what they had lost.

4. Systematic implementation path for safe technical lifting

4.1. 3D dynamic simulation rehearsal of the entire lifting process

The modeling engineer utilizes on-site real-scene scanning data to construct a centimeter-level precision 3D model encompassing adjacent cooling tower pipelines. Within the simulation system, the modeling engineer presets the fully extended state of the crawler crane's outriggers to verify the feasibility of narrow transition channels. The crane operator rehearses on the control room display screen the telescopic trajectory of each boom length as the main hook traverses the pipe gallery truss. Through dynamic simulation, the crane operator discovers that the originally planned boom angle will touch the boundary of the tower crane's counterweight. The construction supervisor reviews the actual lifting eye installation height deviation data against the pre-embedded anchor bolt point cloud map to correct the steel cable traction path. The construction supervisor utilizes storm warning parameters to drive the simulation module to test the swing amplitude of the lifted object under gusty wind conditions. The modeling engineer adjusts the virtual ground bearing strength distribution map based on the latest geological exploration report to avoid outrigger settlement accident points. The modeling engineer loads different working condition counterweight schemes to calculate the instantaneous peak impact load of the slewing mechanism gearbox. The crane operator continuously practices and rehearses the equipment combination and lifting sequence in the virtual environment to solidify a reasonable operation rhythm. The crane operator adjusts the layout of the super-lift counterweight blocks based on system prompts to eliminate lateral tipping warning signals. The construction supervisor verifies the thermal map of track shoe pressure output from the simulation to optimize the laying density and specifications of the subgrade boxes, and marks the critical center of gravity switching period during the turning process of large tanks, requiring the addition of auxiliary lifting points for support [3].

4.2. Establishment of a graded and quantified risk assessment mechanism

During patrol inspections, on-site safety personnel use red warning stickers to mark fall risk points where the depth of edge openings exceeds the height of protective railings. Based on the fluctuation frequency of wind monitoring data, on-site safety personnel determine the hanging position of boundary signs for yellow warning zones. Equipment supervisors use ultrasonic probe thickness gauges to quantify the wear indentations on the neck of lifting hooks, which correspond to blue risk levels. Equipment supervisors update orange risk equipment records based on the internal leakage rate data of the track crane's leg cylinders. The technical expert team analyzes satellite cloud imagery to dynamically trace and delineate the prohibited lifting operation areas corresponding to rainstorm periods. The technical expert team sets automatic alarm thresholds for areas with excessive ground pressure on track shoes by comparing with geological radar scanning data. On-site safety personnel calculate the frequency of amplitude convergence in adjacent tower crane cross-operation areas to configure the response distance of the anti-collision system. On-site safety personnel record the service cycle of hydraulic system seals and label components with failure countdown reminders for replacement. Equipment supervisors collect data on the distribution density of broken wires in the main steel wire rope to generate segmented safety load discount coefficient charts. Equipment supervisors develop a re-tightening operation plan based on the torque decay curve of the counterweight block's fixing bolts. The technical expert team calculates the center of gravity offset trajectory during the turnover of large reaction vessels to simulate the critical overturning angle. The technical expert team integrates historical data from wind speed sensors to establish a prediction curve for the swing amplitude of lifting objects under gusty conditions. Equipment supervisors detect excessive values in the meshing clearance of slewing gears and match them with a graded limit control scheme. Equipment supervisors verify the remaining thickness of the main winch brake pads and correlate it with graded braking response time parameters.

4.3. Integrated application of intelligent surveillance system

The monitoring center screen displays real-time warning light spots generated by the critical section stress data of the tower crane arm exceeding the red threshold. The monitoring center receives a three-level alarm sound triggered by the verticality deviation of the support leg oil cylinder transmitted by the ground sensor. The maintenance team replaces the cooling filter element component based on the abnormal temperature curve of the hydraulic motor pushed by the system. The maintenance team also replaces the Bluetooth temperature tag battery attached to the vibration sensor of the rotary mechanism every month to ensure stable data transmission. The technical team adjusted the preset torque value of the intelligent wrench to match the safety warning parameters of different numbered bolts. The technical team configured a high-definition camera to recognize the deformation size of the hook anti detachment device and activate the locking program. The monitoring center synchronizes the working range coordinates of multiple tower cranes to establish a three-dimensional anti-collision electronic protective fence. The monitoring center stores the swinging trajectory of the suspended object during strong wind periods to provide historical data for optimizing the construction plan. The maintenance team cleans the concrete residue attached to the weight sensor terminal to restore weighing accuracy, and uses calibration instruments to calibrate the pulse counting error corresponding to the worn gear rack of the amplitude limiter. The technical team implanted the gust mutation parameters collected by the micro meteorological station to correct the lifting stability model, and the technical team automatically switched to the moisture-proof mode of the outdoor distribution cabinet by associating with the rainfall sensor data. The monitoring center detected an abnormal distribution of ground pressure on the track shoes and immediately sent a shutdown inspection command. The monitoring center determined the safe load reduction range for the section with excessive wire breakage based on the waveform diagram of the online wire rope inspection [4].

4.4. Standardized operating procedures and emergency drills

The safety supervisor shall prepare a site layout checklist that includes a schematic diagram of the full extension dimensions of the crawler crane legs. The safety supervisor shall specify the mandatory process of manually confirming the installation of the counterweight locking pin in place before lifting. The homework team uses pre tied balance beams to shorten the preparation time for switching the main hook to grab mode. The homework team checks the threshold of the wind speed alarm and implements the rigid standard of stopping the lifting of steel above level six wind. The emergency team simulates the main wire rope breaking scene every month to practice the intervention procedure of operating the dual braking system, and the emergency team drills the full set of actions of emergency landing of heavy objects to the preset buffer bunker in the rainstorm raid drill. The safety supervisor introduces a visual command system to unify the whistle sound and light signals of multiple devices working together. The safety supervisor requires that each operation step must retain image records to form a traceable file. When the operation team performs the over lifting condition, two people must double check the locking status of the over lifting counterweight radius dial. The operation team insists on clearing the ground cable trench cover obstacles with the leading vehicle during transportation in narrow spaces. The emergency team regularly tests the efficiency of the multi cylinder synchronous lifting and recovery plan when the support leg suddenly sinks. The emergency team uses fire water curtains to isolate electrical fires and transfer valuable hydraulic pump stations. The operation team monitored the distance between the boom and the high-voltage line during the lifting of the ultra long components, triggering an automatic power outage. The operation team counted the number of components of the wind turbine blade flipping special fixture according to the process diagram. The safety supervisor organized an assessment of the brightness level of the laser positioning guidance device installed in the blind spot of night lighting, and mandated that the crane key must be removed and returned to the dispatch room for physical isolation measures after the operation [5].

5. Conclusion

The safety lifting of large lifting machinery combines the dual attributes of high-precision technology and refined management. Research elucidates the theoretical pillars of mechanical properties, process elements, environmental correlations, and process control. The practical process highlights key bottlenecks such as deviation in load determination, deviation in scheme execution, insufficient reliability of safety devices, and inefficient command coordination. The systematic path advocates for the simulation and validation of three-dimensional simulation technology, a graded and quantified evaluation mechanism to lock in risk nodes, an intelligent monitoring system to achieve real-time perception and intervention of the process, and standardized procedures and emergency drills to solidify safety behaviors. Technological progress drives the expansion of safety boundaries, deepens human-machine collaborative intelligent decision-making, improves the full chain responsibility mechanism, and constitutes an important direction for enhancing the safety resilience of large-scale lifting in the future.

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