Damage Assessment for Refinement Towers in Oil Installations using 3D Laser Scanning Technique

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ABSTRACT

Terrestrial Laser Scanning (TLS) can be used to detect damage and analyze volumetric changes in large structural test specimens. Compared to traditional imaging and surface analysis methods, the primary reason for using 3D scanning is the difficulty of attaching targets to towers of varying heights, as well as the fact that some towers are covered with insulating materials that obscure key landmarks. In addition, the large number of incoming and outgoing pipes and stairs attached to the towers further complicates traditional assessment methods. This research focuses on assessing the damage to the three refining towers at the Baiji Refinery facility. Scanning was performed using a 3D laser scanner with HDR color imaging, capturing data from thirteen stations positioned around the towers. The data were exported for registration and processing to create as-built drawings that provide a visual inspection of the deviations for each tower, the second tower (V6) exhibited the maximum inclination compared to the others. The point cloud data were converted to solid geometry for further analysis. The analysis revealed that V3 tower has a regularly increasing slope in a linear pattern. V6 tower shows a gradual slope in the first seven courses at a constant rate and in a fixed direction, followed by a more drastic change from the middle of the tower to the top. The V8 tower exhibits a gradual increase in tilt from the base, which stabilizes from the middle to the top. Based on these results, which are consistent with the visual analysis and compared to the international standard for tilt value, tower V6 must be taken out of service. The other towers can be rehabilitated with periodic monitoring to ensure stability before being returned to service at the refinery.

Keywords-Terrestrial Laser Scanner (TLS); 3D modeling; tower; Baiji refinery; as-built drawing

I. INTRODUCTION

Damage assessment is an important part of asset maintenance. A significant percentage of large- scale factory and infrastructure projects often exceed budgets and fall behind schedule due to unforeseen complications during the construction phase. When these complications necessitate design changes or repairs, the resulting additional costs can be substantial. Industrial assets and infrastructure in any sector tend to deteriorate or become vulnerable to damage or failure [1]. To assess the consequences of such damage and plan appropriate remedial actions, it is necessary to obtain accurate and up-to-date documentation of the affected facilities [2]. The oil and gas industry are one of the most important sectors globally, meeting the daily energy needs of people worldwide. Investment in this sector is important due to its functional capabilities and its crucial role in sustaining modern life [3]. The rapidly growing demand for energy requires the oil and gas sector to increase production by building new facilities or expanding the existing ones. However, this often requires extensive rehabilitation of the latter, which includes repairing damaged facilities or adding new ones [4]. This paper describes the application of modern technologies, in particular 3D laser scanning, as an engineering tool to assess the inclination of the refining towers at the Baiji refinery. 3D laser scanning is a technology that provides the most accurate description of an object in the least amount of time compared to traditional methods [5]. It can be performed on the surface of an object, allowing the collected data to be used for analysis or inspection for multiple purposes [6]. As a non-destructive, non-contact technique, 3D laser scanning allows rapid data acquisition to measure the shape of an object as a set of spatial points [7]. The resulting point cloud data can be digitally converted into 3D models [8], which accurately represent the real object at a given point in time [9]. By comparing the real object with its designed model, deviations can be detected, enabling accurate and reliable decision-making. The Baiji refinery is located in Salah al-Din Governorate, approximately 130 km north of Baghdad, along the main road connecting Baghdad to Mosul. The refinery towers have undergone so much damage during war that it would take years to be again operational [10]. This study presents a new technique for computing the inclination of refinement towers using 3D laser scanning. The technique is applied to evaluate the damage sustained by three refining towers at the Baiji Oil Refinery, with the goal of making the facility operational again after several years of inactivity.

II. METHODOLOGY

A. Site Preparation and Planning

The information regarding the towers (V3, V6, and V8) in unit three at Baiji refinery is presented in Table I. The towers were monitored from 13 laser scanner stations positioned around their circumference to ensure complete coverage from all sides. The distribution of these scan stations was selected to provide at least 20% to 70% overlap, as shown in Figure 1. The results obtained from the 3D laser scanning were then compared with those of traditional methods, such as visual analysis. Conventional techniques, including the usage of optical instruments, such as total stations, were excluded from the comparative analysis due to their incompatibility with the objective of this study.

TABLE I. TOWER DATA

Identification number (Tag)	**O3-V3, V6, V8**
Location of installation	Baiji
Rules/Code	ASME VIII Div 1
Item No	O3-V3, V6, V8
Test pressure	517.5 kPa (g)
External insulation	Yes
Height	25 m to 28 m
Capacity	74.7 m^3
Head thickness	Upper head 09 mm, Bottom head 15 mm
Year of built/operation	1985
Design temperature	285 °C
Corrosion Allowance for Vessel	3.0 mm
Material	SA 515 Gr 60
Shell thickness	15 mm, 13 mm, 10 mm from bottom to top

The Trimbles 3D Laser Scanner TX6, operating at a rate of 500,000 points per second, was selected based on its advanced capabilities, including a high-resolution scanner with an integrated HDR color camera. This particular model was chosen in accordance with the height of the towers and the optimal distance, ensuring that the laser maintained its resolution of 120 m [11]. As a result, it was possible to determine the optimal distance between the towers and the laser scanner.

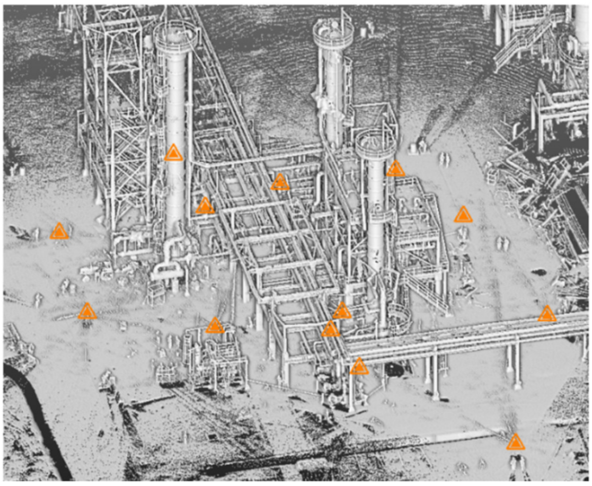

Fig. 1. The three towers and 13 scan stations.

B. Data Collection Process

The data collected from the laser scanner, including images and point clouds, were exported to the processing unit for registration. Sphere targets were used to apply automatic registration processing, achieving an overall cloud-to-cloud error of 1.42 mm. The overlap achieved ranged from 20% to 66%, with a confidence level of 80% to 99%, enabling the creation of as-built drawings for the unit using specialized software, Trimble RealWorks (TRW). TRW a is a set of native software for the Trimble TX6 3D scanner, allowing data to be captured without changing the file format. It also provides comprehensive tools for point cloud processing, recording, and analysis. The software's capacity to manage substantial volumes of point cloud data allows it to perform tasks, such as classifying indoor or outdoor objects by category, creating 2D or 3D cross-sections, performing measurements, and extracting specific objects [12]. The tower area of interest was isolated for data processing and obstacle removal, as displayed in Figure 2.

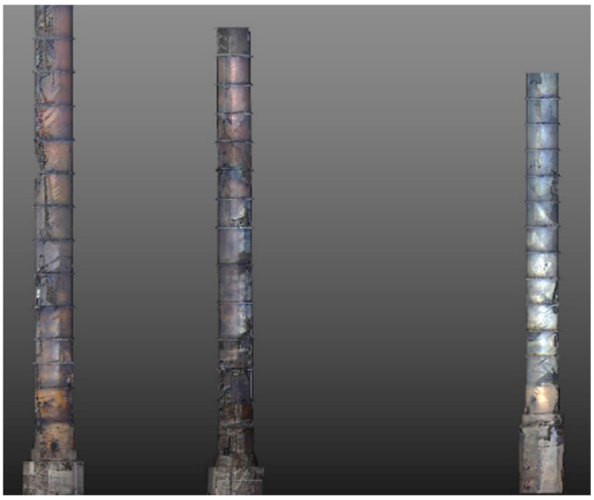

Fig. 2. The three towers after cleaning up.

A comprehensive examination of the inclination of the towers was conducted, encompassing the visualization of all sides: front, back, right, left, top, and bottom. The towers were then rotated along the vertical axis, aligning two towers at a time, to ascertain whether a visually perceptible inclination was present. As depicted in Figure 3, tower V8 is visible, followed by tower V6 in what appears to be a straight line. However, a discernible visual inclination is apparent in the area marked by the red rectangle. Upon zooming out, it becomes evident that the two towers are not aligned in a straight line. Instead, an observable inclination is present on two distinct sides, at the top and bottom, with the towers converging in the medial plane, as presented in Figure 4.

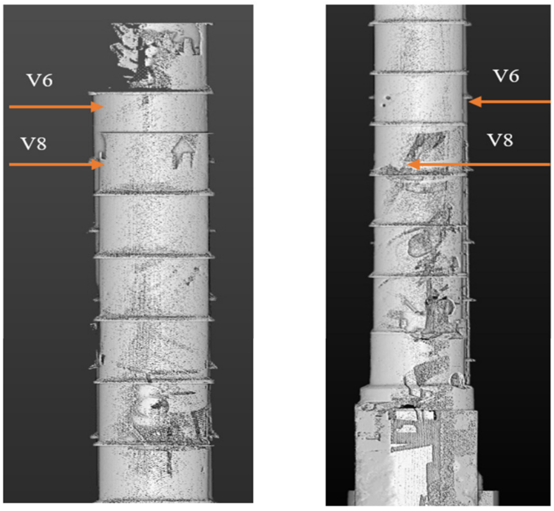

Fig. 3. View from the east.

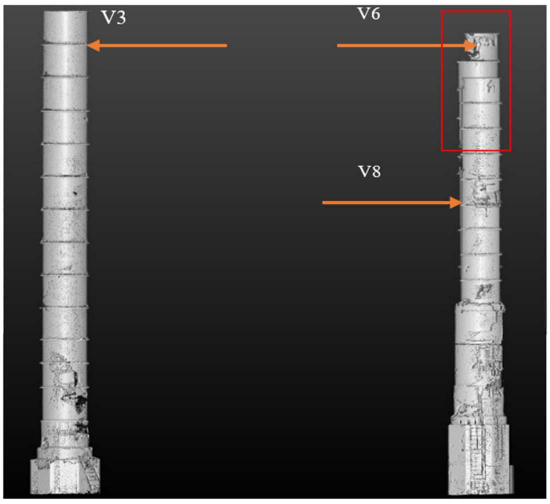

Fig. 4. Towers V8 and V6 are applicable.

When observed from the north side, the southern portion of tower V3 appears obscured by the northern portion of tower V6, as portrayed in Figure 5. The visual overlap makes it difficult to detect any tilt, but when the image is amplified through the use of specialized software, the inclination becomes discernible, beginning at course 5. Furthermore, as shown in Figure 6, tower V3 appears on the left side. It is noteworthy that the patterns observed in the south and west are analogous to those seen in the north and east.

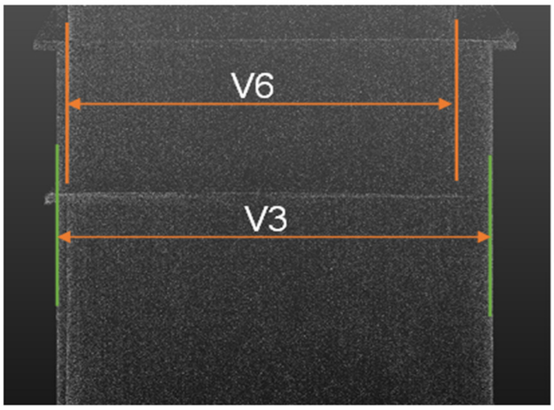

Fig. 5. View from the north.

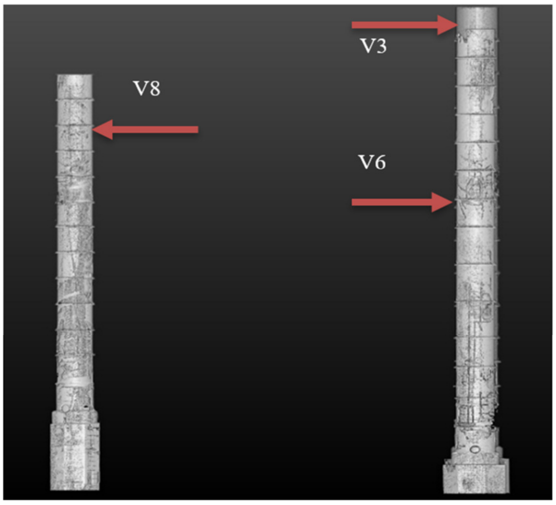

Fig. 6. The appearance of the incline between the two towers from the left.

Conversely, the front view of the towers can be applied to the 2D network of perpendicular straight lines, with the vertical line serving as a reference for detecting indications. In this view, tower V6 exhibits a more pronounced inclination compared to the other towers, as illustrated in Figure 7. This observation underscores the necessity for the employment of supplementary techniques and tools to further analyze the tilt and determine its direction [13].

C. Damage Assessment and Volumetric Analysis

The calculation of inclination was performed using the TRW processing program. The program's 3D modeling tools allow geometries, such as octagons and cylinders, to be created and fitted to a selected point cloud. These geometries can then be duplicated, modified, moved [14, 15], and the towers will be displayed in solid geometry, with separate top views for each. The octagonal representation signifies the concrete base fixed on the ground, the red cylindrical signifies the first concrete base fixed on the octagon, and the green cylindrical the courses of the towers. This enables the observation of the inclination of each tower in a specific direction and magnitude. The cylindrical concrete base, being vertical and without deviation or inclination, serves as the reference point for measuring inclination, as evidenced in Figure 8.

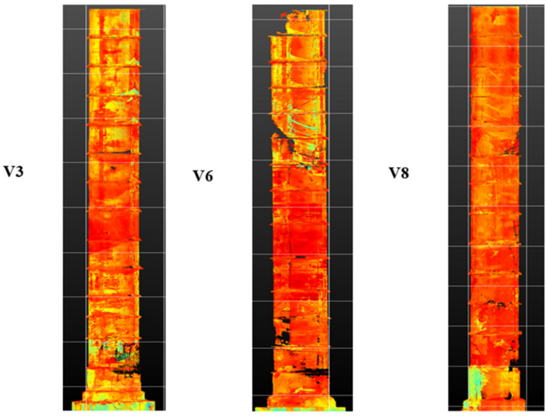

Fig. 7. Inclination by applying towers to a network of perpendicular straight lines.

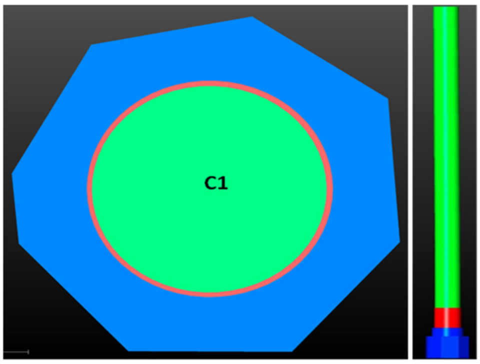

Fig. 8. Front and top view, illustrating the concrete base and the first course in green for tower V3.

TABLE II. INCLINATION VALUES AT EACH COURSE IN TOWER V3

Course no.	Inclination towards the north	Course no.	Inclination towards the north
1	Less than 1 cm	8	Less than 1 cm
2	Less than 1 cm	9	1 cm
3	Less than 1 cm	10	1 cm
4	Less than 1 cm	11	1 cm
5	Less than 1 cm	12	1 cm
6	Less than 1 cm	13	2 cm
7	Less than 1 cm		

The inclination was calculated by taking a cross-section for each cylinder course and matching it with the cross-section of the reference concrete cylinder base, measuring the maximum disparity in the center between the two cross-sections [16]. The horizontal shift for each course was determined by calculating the difference in X and Y coordinates of each course center. The direction of the inclination was subsequently determined using the arctangent law. This procedure was applied to all towers to determine the inclination at each cylinder course. Tower V3 exhibited an inclination of less than 1 cm towards the north. This inclination remained constant until course number 9 at which point it increased to 1 cm. At the tower's zenith, the inclination reaches 2 cm, maintaining the same direction. No discernible inclination was observed towards either east or west, as presented in Table II and Figure 9.

For tower V6, no inclination is observed in the first course (C1), as shown in Figure 10.

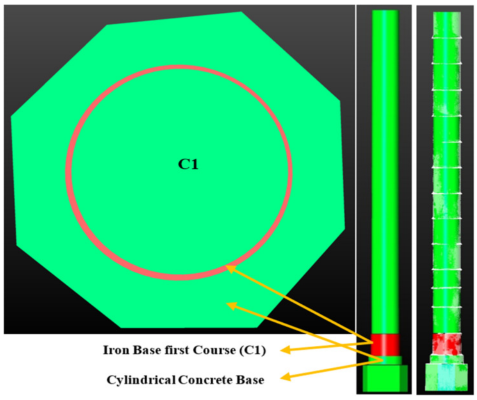

Fig. 9. Front and top view illustrating the concrete base and the first course in green for tower V3.

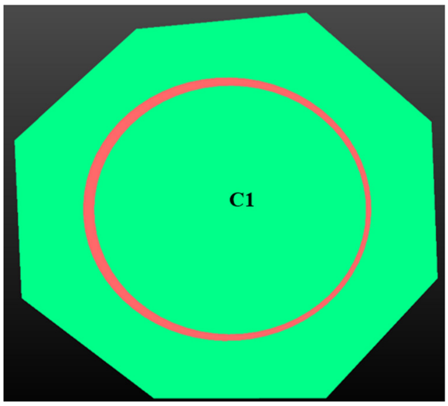

Fig. 10. Top view showing the concrete base in red and the first iron base in green in tower V6.

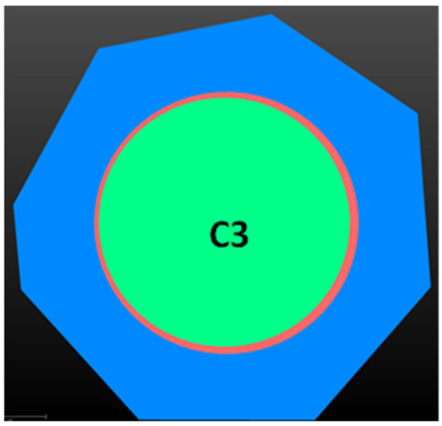

Fig. 11. The third course leans to the south 3 cm.

However, the inclination increases by 2 cm towards the south in the third course (C3). This inclination then continues to increase by 1 cm with each subsequent course in the same direction, as depicted in Figures 11 and 12. In the ninth course (C9), the inclination increases to 2 cm and then exhibits a return to an increase of 1 cm per course in the tenth course (C10). By the eleventh course (C11), the inclination has increased to 13 cm in the southern direction, with no inclination being observed in the eastern or western directions, as portrayed in Figure 13 and Table III.

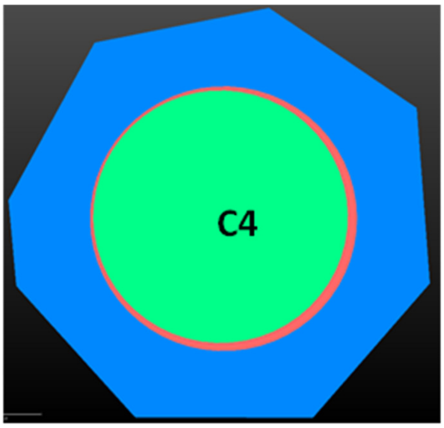

Fig. 12. The fourth course tends to the south 2 cm.

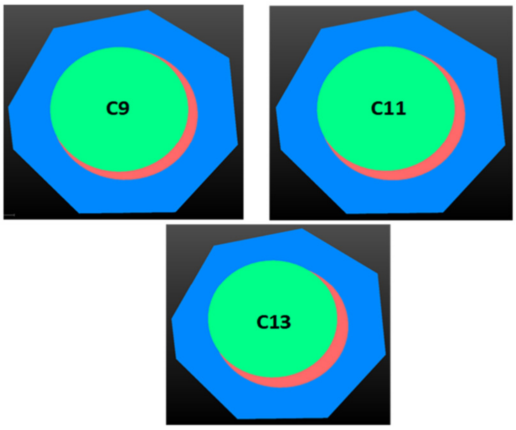

Fig. 13. The increase in inclination in the V6 tower.

TABLE III. INCLINATION VALUES AT EACH COURSE IN TOWER V6

Course no.	Inclination toward the south	Course no.	Inclination toward the south
1	0	8	9 cm
2	0	9	11cm
3	2 cm	10	12 cm
4	3 cm	11	13 cm
5	5 cm	12	15 cm
6	6 cm	13	16 cm
7	7 cm		

In the tower V8, no inclination is observed in the initial course (C1), as illustrated in Figure 14. The inclination begins in the second course (C2), with a slope of 1 cm to the north. This inclination remains constant in the third course (C3) and subsequently increases to 2 cm in the fourth course (C4), where it remains stable. By the eighth course (C8), the inclination reaches 3 cm and remains constant toward the top of the tower, all in the same direction. No discernible inclination is observed in the east or west directions, as presented in Figure 14 and Table IV.

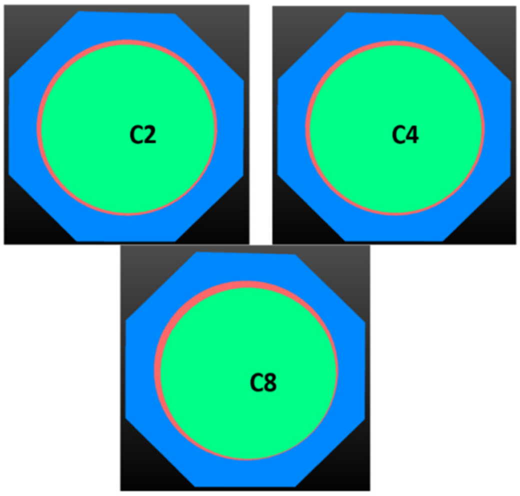

Fig. 14. The increase in the inclination in the V8 tower.

TABLE IV. INCLINATION VALUES AT EACH COURSE IN TOWER V8

Course no.	Inclination toward the south	Course no.	Inclination toward the south
1	0	8	3 cm
2	1 cm	9	3cm
3	1 cm	10	3 cm
4	2 cm	11	3 cm
5	2 cm	12	3 cm
6	2 cm	13	3 cm

III. STATISTIC COMPUTATION

The statistical analysis for the inclination data of the three towers (V3, V6, and V8) is:

A. Descriptive Statistics (Mean, Median, Standard Deviation, Range)

Table V shows the measured descriptive statistics.

TABLE V. THE STATISTIC VALUE OF THE TOWERS V3, V6, V8

Towers	Mean	Median	Standard deviation	Range
V3	0.64 cm	0 cm	0.63 cm	2 cm
V6	7.62 cm	7 cm	5.3 cm	16 cm
V8	2.15 cm	2 cm	0.95 cm	3 cm

B. Trend Analysis

The trend pattern for the inclination of the towers is examined by implementing the linear regression fundamental statistical method. A linear regression model:

$$y = mx + c \quad (1)$$

is fitted to the data on inclination (y) and course number (x), as shown in Table VI.

TABLE VI. LINEAR REGRESSION MODEL FOR TOWERS V3, V6, V8

Towers	m=Slope (cm/course) $(N\sum(xy)-\sum x\sum y)/(N\sum x^2-(\sum x)^2)$	R-squared $1-(\sum(y_i-\hat{y}_i)^2/\sum(y_i-y_i)^2)$	c=intercept $(\sum y-m\sum x)/N$
V3	0.13	0.13 cm	-0.45 cm
V6	2.97	-2.68 cm	-13.17 cm
V8	0.23	0.58 cm	0.54 cm

R^2=-2.68 indicates a poor fit for linear regression, polynomial regression may be more appropriate

The present analysis confirms that tower V6 is structurally unstable and must be removed, while towers V3 and V8 can be rehabilitated with periodic monitoring.

IV. RESULTS AND CONCLUSIONS

Based on the recorded data from the visualization, software processing and calculations, it is clear that all the towers have unique tilt patterns, each of which affects their operational safety and future maintenance requirements. In tower V3 the deviation increases regularly, with a small value of 0.08 cm per course, reaching a maximum inclination of 1 cm. This indicates that the tower is relatively stable. However, there is a noticeable shift in the final trajectory, where the tilt suddenly increases to 2 cm. This deviation warrants further study to determine its cause. Nevertheless, the tilt remains within acceptable limits, making tower V3 suitable for restoration. In contrast, tower V6 shows significant structural instability. The first seven courses demonstrate a gradual inclination, with a constant rate of 1 cm and a fixed direction, with a non-linear increment. From course 8 to course 13, the inclination increases at a higher rate, indicating a more drastic structural change. The maximum inclination value reaches 16 cm, far exceeding the international standard of 3 cm for oil refinery towers. This indicates foundation instability and it is recommended that tower V6 be demolished to prevent potential hazards. Tower V8, on the other hand, is relatively stable, with a controlled and gradual increase in tilt. The inclination starts at 2 cm and stabilizes at 3 cm by the eighth course. This gradual inclination is the result of deviations in the previous courses, and no sharp inclinations are observed. Tower V8 can be safely returned to service with appropriate repairs and periodic monitoring, as its tilt remains within acceptable limits. In conclusion, towers V3 and V8 can be rehabilitated with periodic monitoring, while tower V6 poses a significant risk and should be decommissioned. These results provide a solution to the structural concerns at the Baiji refinery facility with the usage of advanced 3D scanning technologies to monitor the health of industrial structures. Future work should focus on installing long-term monitoring systems to detect early signs of structural damage and prevent catastrophic failures.

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