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# PROPOSED APPROACH FOR POSITIONING ANCHORAGE SYSTEM IN CONCRETE

M. HABIB<sup>1</sup>, A. MALKAWI<sup>2</sup>, M. AWWAD<sup>3</sup>

The problem of setting out in civil engineering applications has been addressed in the literature for a long time. However, technological development has provided researchers with an opportunity of having other procedures in line with modern techniques in surveying sciences. One of the most important procedures in erecting steel structures, bridges, and precast columns of a building is the accurate placement of the anchorage system in concrete. The traditional method for staking out anchor bolts relies on sight rails, string lines, and tape measure. The precision of this art depends not only on the accuracy of observed offset distances during layout operations but also on the centerline of the anchoring template itself. Nowadays, the process of designing structures is executed using software that can perform a digital plan in CAD environment, where the coordinates of each anchor bolt can be defined. This research presents an accurate approach of positioning anchor bolts based on the second problem in surveying and total station. Error analysis and field application are described to evaluate the performance of the proposed method. However, the results indicate that the developed technique increases productivity, reduces the cost, and improves the positional accuracy.

**Keywords:** anchor bolts, setting out, and column base plate.

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## 1. INTRODUCTION

Nowadays, the rapid development of information technology has a significant effect on surveying sciences, both in the field of observing instruments, data capturing, processing, visualizing, and managing. This situation leads to a substantial rise in productivity and enhances the accuracy and quality of the spatial data by making digital mapping. Since engineering projects lean on geodetic control points, their precision will directly affect the quality of accomplished tasks. Indeed, it is difficult to rely on control points for survey works in civil engineering due to the spacing between them. Traversing is considered a vital issue that has a high priority for setting out works because it provides a means to extend the horizontal control and to prevent gross errors. Hence, one of the fundamental tasks of the surveyor is to make the correct decision for selecting a suitable method and equipment to get the required accuracy (NSPS, 2002).

During the last years, special attention was given to anchorage systems in concrete due to their various applications in many construction works (Solomos & Berra, 2006). The anchoring system consists of a set of anchor bolts inserted in a reinforced concrete foundation to connect a steel plate with the structural element. The column base plate, Fig. 1, is the most vital structural part (Lee & Stojadinovic, 2008), generally utilized to distribute the axial load over a higher supporting spot and to secure the column to the reinforced concrete base. On the other hand, anchor bolts are used to ensure excellent strength and stability of the structure (Munemoto & Sonoda, 2017). Typically, anchor bolts and base plates are among the last components of a structural steel building to be designed, and yet they are the first items to be placed (Collins & Schlafly, 2010). Current standards specify the type, number, size, and length of the anchor bolts that are required to fix the structural elements in their place (ACI 318, 2014). The accurate placement of the anchor bolts is considered as the primary component to safely erecting and controlling the verticality of a building (Fisher & Kloiber, 2006). It is not allowed to commence the erection works unless the errors in the location and level of the anchors are within the allowed ones (BS EN 1090-2:2008).

In fact, setting out the anchor plate even when the best of erection conditions is achievable will remain a challenging task. The proper installation of the anchor bolts requires the availability of a firm, level, dry, trained steel erector, and uncongested job site. However, it is known that the vast majority of the construction sites will not comply with the previously listed conditions. Hence, misplaced anchor bolts

are likely to occur (Putkey, 1993). This mistake may become very difficult to fix once the concrete is hardened, considering both structural and economic aspects. Therefore, an accurate layout of the bolts is a very significant in-situ task for engineers. Although both American Concrete Institute (ACI 117, 2015) and American Institute of Steel Construction (AISC 303, 2016) standards have provided limitations on the allowable error while staking out these bolts, neither has suggested a particular method for setting out the anchor bolts accurately.

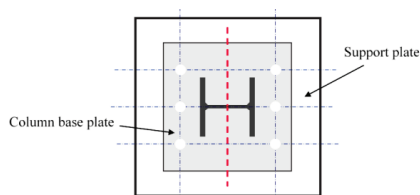


Fig. 1. Steel column base plate

The baseline and offset method is the common technique used for staking out anchor bolts in site-cast concrete that relies on sight rails, string lines, and measuring tape. The batter boards are carried out to place the centrelines of the anchorage template in a designed position using a theodolite, tape, and level instruments. As a result, the templates are placed at intersecting string corners, as demonstrated in Fig. 2, then the concrete is cast. Finally, when the concrete base becomes dry and strong the level of the column is controlled through the leveling nuts beneath its base as shown in Fig. 3, then the nuts above the base are tightened, and non-shrink grout underneath the steel plate is filled to guarantee a full contact with the footing system (Shaheen et al., 2017).

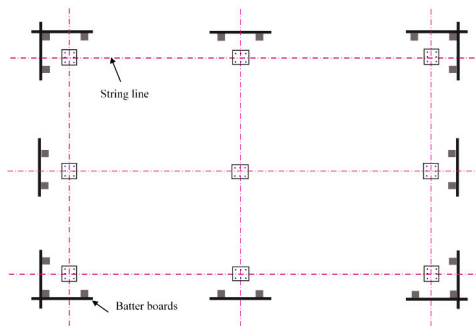


Fig. 2. Batter boards and string lines for the layout of plates

The most common errors in this method that occurred on the horizontal position of a template come from the accuracy of the reference lines and weathering conditions in the site. The vertical location of the template is achieved using a level instrument and a wooden carrying base; nevertheless, there is a possibility to modify the elevation of nuts, within a limited range, under the column base after the concrete has hardened. This study is intended to provide a precise procedure for horizontal setting out of anchor bolts in site-cast concrete by using the coordinate method that is based on the second problem in surveying and total station. A comparative study of the proposed technique with the traditional approach is conducted to evaluate its effectiveness.

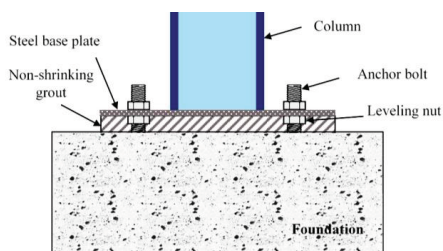


Fig. 3. Installation of steel column into a reinforced concrete foundation

## 2. MATERIALS AND METHODS

The staking out is the first stage for the erection of engineering projects to ensure that the designing element will be placed in the correct position at the right elevation. However, the construction process should be achieved with a high level of awareness about the importance of the precise layout of the anchor bolts (Leinonen et al., 2003). Firstly, control points are established according to the site layout plan by considering the permanent structures and the relevant lengths of structural parts as specified in the AutoCAD drawings. Moreover, Computer-Aided Design (CAD) is a powerful tool to create, optimize, modify, and analyze the design (Moreno and Bazán, 2017). The most commonly used CAD software is AutoCAD that offers many functions for achieving computer models defined by geometrical parameters. It is widely applied in the civil engineering field to produce topographic site maps, draw engineering structures, and simulate in 3D the movement of the object during a design process. Therefore, it is more suitable to find other methods and alternatives for computing, balancing, and staking out survey measurements based on AutoCAD tools.

## 2.1. STUDY SITE

The study area is located in Syria - Adra industrial city at about 33° 39' 6".48 N and 36° 34' 45".48 E. This site contains a set of steel warehouses with different dimensions and steel sections, which was implemented by the author as per an agreement with the owner company. However, another sub-contractor utilized the traditional method to layout a single warehouse.

## 2.2. THE PROPOSED APPROACH

The operation of setting out of a structure according to the prepared designs is an essential part of the civil engineering work. This work must be executed accurately because any error can be costly and time-consuming to repair. The coordinates of each anchor bolt are extracted from CAD drawing; therefore, it is more accurate to apply a coordinate method for staking out anchor bolts plate in the correct position by a total station. Typically, the coordinate file for the needed bolts will be uploaded into the instrument from the computer, and then it will be ready for setting out the works. Fig. 4 presents a schematic diagram for the general methodology of the framework in this research to set out anchor bolts.

The key to set the anchor bolts precisely in concrete is to do it before the pour starts, where the precise location of them has an essential role in erecting the steel structure. The positional error of bolts occurs when the measured deviation from the specified location or alignment is more than the defined construction tolerance. The degree of accuracy that can be acquired relies on the observation instrument and the skill of the surveyor in choosing an appropriate procedure for the project. The tolerance should be taken into account to avoid errors in the layout of anchor bolts. In general, the allowable errors in staking out of anchor bolts that given by the AISC are more restrictive than provided by the ACI. Codes of practice specified that the misplacing of anchor bolts by more than  $\pm 3$  mm from the position designated on the plan is not accepted (Basham, 2016). Furthermore, the center point of a grouped anchor bolts shall not be shifted over  $\pm 6$  mm (BS EN 1090-2:2008). These limits are the main objectives to be fulfilled by the proposed approach.

Formwork is used to support the structure through its erection phases. Consequently, to maintain the anchor bolts in position during casting, additional lateral bracing is required to ensure stability and alignment of form against the pressure of the poured concrete and working loads. After the shuttering has been built, aligned, and braced, the two wooden pieces as a carrying base of the plate with a width

of 8 cm and a thickness of 4 cm are nailed firmly to it, as indicated in Fig. 5-a. They are placed at a convenient elevation using leveling equipment and a nearby benchmark that was established relative to a specified vertical datum.

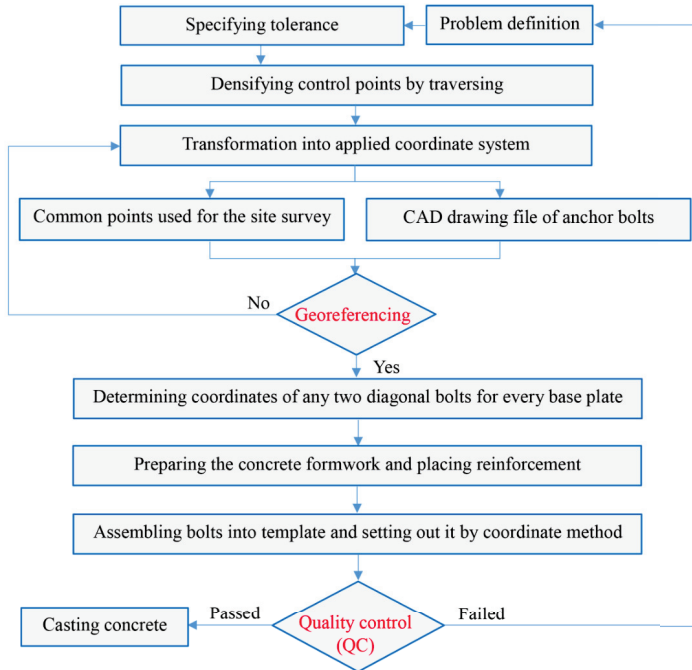


Fig. 4. Workflow for the layout of anchor bolts

In order to accurately stake out the position and orientation of anchor bolts that assembled onto the fabricated template for matching the bolt holes on the column base plate, it is enough to assign the coordinates of any two diagonal bolts as seen in Fig. 5-b. Subsequently, the second problem in surveying or inverse solution between the control station and coordinated bolt is calculated to give the distance and azimuth (Ghailani & Wolf, 2012). The control points are created on the site with respect to the applied coordinate system to use them as a station and orientation for establishing other points precisely, such as the layout of anchor bolts. The location of control points should be carefully selected to get the desired benefits from this approach. The main obstacle in using the total station for setting out anchor bolts is

the human error emerging from holding prism pole over them. Therefore, the proposed approach includes a special adapter of mini prism that is applied to overcome the centering error of range pole and to increase the positioning accuracy, as shown in Fig. 6. In the field, the layout process of anchor bolts involves the occupying of a defined control station, taking a backsight on an orientation point, turning off the direction, and measuring the distance to set the specified bolt.

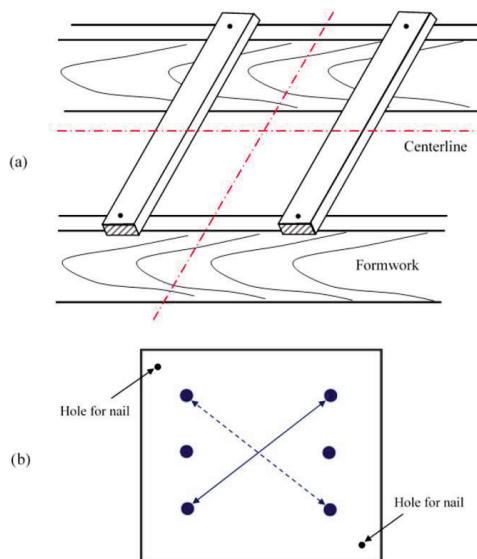


Fig. 5. (a) Wooden cross pieces to control the plate elevation, (b) layout of anchor bolts using coordinate

Firstly, the total station is set up over a known point and sight to another one as an orientating backsight. The forced centering of a prism over orientation point using a tribrach mounted on the tripod will dramatically reduce the effect of plumbing errors (García et al., 2018). Secondly, after assigning the coordinates of the anchor bolt 1 to be staked out, Fig. 7, the total station program will automatically calculate the parameters required for setting out. These parameters define the moving amount of a template in one of two sides right/left or up/down. After completing the layout of bolt 1, the plate should be nailed to the form. In the same manner, the bolt 2 is located by rotating the plate in a clockwise or counterclockwise direction. After that, the template is fixed to a wooden carrier with another nail hammered into it. Finally, each anchor bolt is tied to the reinforcing bars with wires or welding to keep

it in place. Additional care should be obeyed during the concrete pouring by directing the pumping pipe away from the anchor bolts. As a verification process for the computations and fieldwork, it is preferable to check the staked location of bolts by determining their coordinates from various control points and comparing them with designed ones or by measuring the distances between centerlines of anchor bolts on the site.

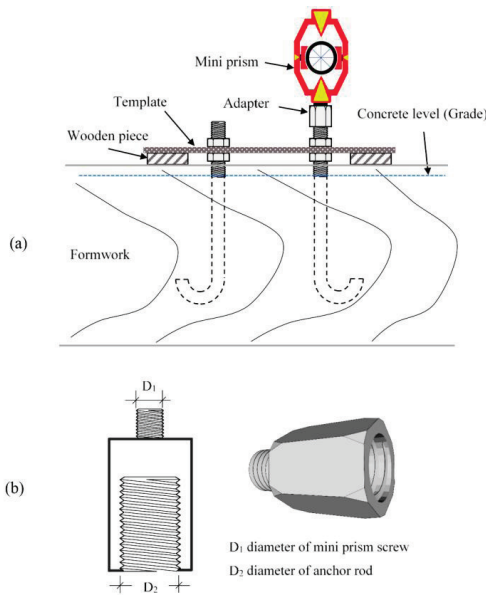


Fig. 6. (a) The adapter of the mini prism for the layout, (b) cross-sectional side view of the adapter

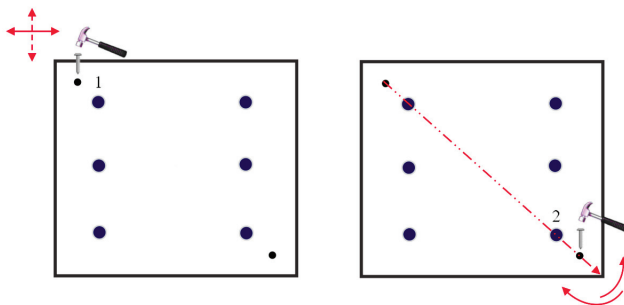


Fig. 7. Layout steps of the template



The error analysis of setting out and as-built survey process will be applied for testing the method reliability. The measurement error represents the deviation between the most probable value of a quantity and the value acquired by observing it. However, the saying “errorless measurements are impossible” is a fundamental concept of error theory (Baykal et al., 2005). One of the most important works of the surveyor is the decision making for choosing an appropriate procedure and adequate equipment to fulfill the required accuracy, which indicates the closeness between the measured values and their true ones. The standard deviation is a measure of the accuracy, which should not be higher than the confidence interval in setting out and as-built survey of anchor bolts. The two fundamental problems in surveying, Fig. 8, are applied to layout and final survey of anchor bolt P from known station A ( $x_A, y_A$ ), after orienting on another point B with defined coordinates, by observing the horizontal distance  $s$  from A to P and the horizontal angle  $\beta$ . The site grid system is preferred to be a local site grid to get a standard deviation  $\sigma_{x_A}$  and  $\sigma_{y_A}$  of coordinates of the control point A equal to  $\pm 1$  mm. Practically, a total station is used for staking out and as-built survey of anchor bolts, where its distance accuracy and angle measuring precision should be  $\sigma_s = \pm (2 + 1\text{ppm})$  mm and  $\sigma_r = \pm 2'' \approx \pm 6''$  or better respectively (Kala, 2009). In this study, the accuracy of the anchor bolt layout accuracy is calculated for the following assumptions:

- ⊕ Centering errors at the layout bolt P and the orientation point B are omitted because the forced centering of a prism is adopted.
- ⊕ Centering error at the station point A can be ignored, as its effect is minimal.
- ⊕ The maximum distance from the control point to the anchor bolt is 50 m.
- ⊕ The surveyor is professional, and the observations are carried out in suitable conditions.

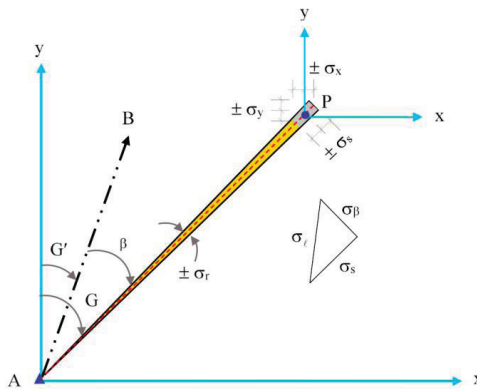


Fig. 8. The layout of anchor bolts P with polar coordinates

The error in the layout of anchor bolt has two components lateral  $\sigma_\beta$  and longitudinal deviation  $\sigma_s$ , or

$$\sigma_\ell = \sqrt{(\sigma_\beta)^2 + (\sigma_s)^2} = \pm 2.1 \text{ mm}$$

$$\sigma_\beta = s \cdot \frac{\sigma_r}{\rho''} = \pm \left( 50000 \times \frac{2}{206265} \right) = \pm 0.5 \text{ mm}$$

Control point A position error equals

$$\sigma_A = \sqrt{\sigma_{x_A}^2 + \sigma_{y_A}^2} = \pm 1.4 \text{ mm}$$

Then, staking out the accuracy of anchor bolt  $\sigma_P$  is

$$\sigma_P = \sqrt{(\sigma_\ell)^2 + (\sigma_A)^2} = \pm 2.5 \text{ mm}$$

The as-built coordinates of anchor bolts P from polar coordinates, azimuth G and distance s, are:

$$(2.1) \quad \begin{aligned} x &= x_A + s \cdot \sin G \\ y &= y_A + s \cdot \cos G \end{aligned}$$

The standard deviations,  $\sigma_x$  and  $\sigma_y$ , of coordinates P are determined by applying the error propagation law to Eq. (2.1) as follows (Mikhail & Gracie, 1981):

$$\begin{aligned} \sigma_x^2 &= \left( \frac{\partial x}{\partial x_A} \right)^2 \sigma_{x_A}^2 + \left( \frac{\partial x}{\partial s} \right)^2 \sigma_s^2 + \left( \frac{\partial x}{\partial G} \right)^2 \sigma_G^2 \\ \sigma_y^2 &= \left( \frac{\partial y}{\partial y_A} \right)^2 \sigma_{y_A}^2 + \left( \frac{\partial y}{\partial s} \right)^2 \sigma_s^2 + \left( \frac{\partial y}{\partial G} \right)^2 \sigma_G^2 \end{aligned}$$

Therefore,

$$(2.2) \quad \sigma_x = \sqrt{\sigma_{x_A}^2 + (\sin G)^2 \cdot \sigma_s^2 + (s \cdot \cos G)^2 \cdot \left(\frac{\sigma_G}{\rho''}\right)^2}$$

$$(2.3) \quad \sigma_y = \sqrt{\sigma_{y_A}^2 + (\cos G)^2 \cdot \sigma_s^2 + (s \cdot \sin G)^2 \cdot \left(\frac{\sigma_G}{\rho''}\right)^2}$$

The supposed value of medium azimuth is  $G = 45^\circ$  in the site reference system with a standard deviation  $\sigma_G = \sigma_r = \pm 2''$ . Substituting in Eq. (2.2) and Eq. (2.3) yield

$$\sigma_x = \sqrt{(1)^2 + (\sin 45^\circ)^2 \times (2)^2 + (50000 \times \cos 45^\circ)^2 \cdot \left(\frac{2}{206265}\right)^2} = \pm 1.8 \text{ mm}$$

$$\sigma_y = \sqrt{(1)^2 + (\cos 45^\circ)^2 \times (2)^2 + (50000 \times \sin 45^\circ)^2 \cdot \left(\frac{2}{206265}\right)^2} = \pm 1.8 \text{ mm}$$

As-built accuracy of anchor bolt  $\sigma_P$  is composed of two components  $\sigma_x$  and  $\sigma_y$  or

$$\sigma_P = \sqrt{(\sigma_x)^2 + (\sigma_y)^2} = \pm 2.5 \text{ mm}$$

As mentioned before, it is enough to assign the coordinates of any two diagonal bolts to set the template by the proposed method with an acceptable error of  $\pm 2.5$  mm, as presented previously. Furthermore, the as-built coordinates of any other bolts allow testing the achieved accuracy of the layout by comparing the observed value of coordinates against a known one. Besides, a regular calibration of the survey instruments is critical to guarantee the high precision and reliability of observations to meet the required accuracy (Martin, 2010).

### 3. RESULTS AND DISCUSSION

The coordinate method is relied on modern construction staking out tools utilizing total station to layout anchor bolts of steel warehouses from their coordinates, Fig. 9. The traditional process of setting out the

anchor bolts requires sight rails, a tape measure, and a string line when applied for a warehouse. Moreover, the proposed approach is used to do an as-built survey of bolts to compare the obtained coordinates with designed ones. In order to evaluate the performance of the developed method of layout problem, a comparison analysis between as-built coordinates of 10 bolts for five plates and extracted coordinates from the design plans was conducted. Also, the positions of 10 bolts in warehouses that were set out by the traditional approach were surveyed to compare the current coordinate of each bolt with that obtained from Auto CAD drawings. The differences in easting and northing coordinate for each bolt are calculated to determine the positional vector. The Root Mean Square Error (RMSE) and some statistics about positional errors at the tested bolts are written down in Tab. 1 to validate the developed method. The statistical analysis shows that the traditional way of the layout revealed high error values in some plates that will generate significant financial losses and delay the project delivery time. Errors in distance observations using tape can be caused by many factors, such as incorrect length of tape, variation in temperature, and so on. In addition, the centerline errors in both template directions that are located by theodolite and marked by a string. Furthermore, the lack of fixing the formworks during concrete casting will generate a shift in the position of the anchoring system.



Fig. 9. (a) Accurate layout of anchor bolts using the coordinate method,  
 (b) Assembly process of erected steel warehouse

Table 1. Statistics of positional errors at the tested bolts for the proposed and traditional method

Method	Proposed	Traditional
Minimum absolute error (mm)	1.1	4.0
Maximum absolute error (mm)	3.2	24.0
Mean value (mm)	1.3	4.5
RMSE (mm)	$\pm 1.9$	$\pm 15.4$

## 4. CONCLUSION

The staking out of anchor bolts is a method used to ensure that each template is placed in the right position and to the appropriate level from location data given by design plans. This study presents an alternative procedure for laying out anchor bolts for cast-in-situ concrete using the coordinate method. The proposed approach depends on the extraction of the coordinates of any two diagonal bolts assembled onto a template. The template matches the bolt holes on the column base plate to assign an accurate position and orientation. The coordinates of the anchor rods are determined from the DWG file after changing the reference system of features into the adopted one in the layout process. The obtained accuracy of setting out can be estimated by determining as-built coordinates of any other bolts and comparing them with design values. The results of the error analysis and field application indicated that the presented technique gives an efficient accuracy to meet the standard for staking out of anchor bolts in site-cast concrete.

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