Using Total Station for monitoring the deformation of high strength concrete beams

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ABSTRACT

The movements of an engineering structure, which serves the human life of today's modern world, are exhibiting safe behaviours. Building structures have moved to high-rise, large span and massive scale in the last few decades. In the development of such structures, it will be useful to adopt high strength concrete (HSC) for some of the building components. Monitoring and analyzing deformations of these engineering structures such as high-rise buildings, dams, bridges, industrial complexes are one of the main research fields in geodesy. Deformation analysis process comprises measurements and analysis phases. This paper investigates an integrated monitoring system for estimation the deformation behavior of high strength concrete beams. Two different surveying techniques (one and two total stations measurement techniques) are presented to evaluate the deformation behavior of structural members. The comparison study between the surveying and structural techniques for computation the structural deformation of these beams is introduced and discussed. The results of the practical measurements, calculations and analysis of the interesting deformation using least squares theory and computer programs are presented.

Keywords: High strength concrete, Monitoring, deformation, total station, accuracy

1. INTRODUCTION

High strength concrete is defined as concrete that meets special performance and uniformity requirements that cannot always be achieved by using only conventional materials and normal mixing, placing, and curing practices. These proposals, based on the state-of-the-art information, cover material properties as well as design methods for beams, columns, and walls for concrete grades [8, 9]. The primary difference between high-strength concrete and normal-strength concrete relates to the compressive strength that refers to the maximum resistance of a concrete sample to applied pressure. In many civil structures like bridges, tunnels and dams, the deformations are the most relevant parameters to be monitored [2, 3]. So monitoring the structural deformation and dynamic response to the large variety of external loadings has a great importance for maintaining structures safety and economical design of man-made structures. Dial gauge, accelerometer, Tiltmeter, etc. are traditional tools and methods to measure structure displacement, rotation and together with temperature, wind speed and direction allow the comprehensive investigation of structure dynamics behaviors. These tools must be installed, maintained, and frequently recalibrated to produce reliable results [2]. The collected data from these tools need to be interpreted to obtain direct geometric results which in many cases is very complicated procedure and out of the control of the general structural engineers. Hence, a flexible surveying technique is needed to overcome these obstacles, and make the process of measurements easier and more accurate.

2. PRE-ANALYSIS STUDY OF THE USED SURVEYING TECHNIQUES

Pre - analysis of the surveying measurements is the analysis of the component measurements before the project is actually undertaken. Main items to be considered in the pre-analysis study of a certain survey project are: Possible surveying techniques, and thus the corresponding mathematical model, and available instruments (cost, simplicity and the precision of a single measurement) [2, 8].

2.1 One total station technique

From figure 1, the X-axis is chosen arbitrary as a horizontal line in the direction of the base of the monitoring building, where the Y-axis is a horizontal line perpendicular to the building base direction and positive in the direction towards the monitoring object, and the Z- axis is a vertical line determined by the vertical axis of the instrument at occupied station. There is a known coordinate's point (A), and these coordinates are (XA, YA, ZA). From this point, the coordinates of any point (B) and its accuracy can be determined this case has a unique solution, so the multivariate propagation technique will be used.

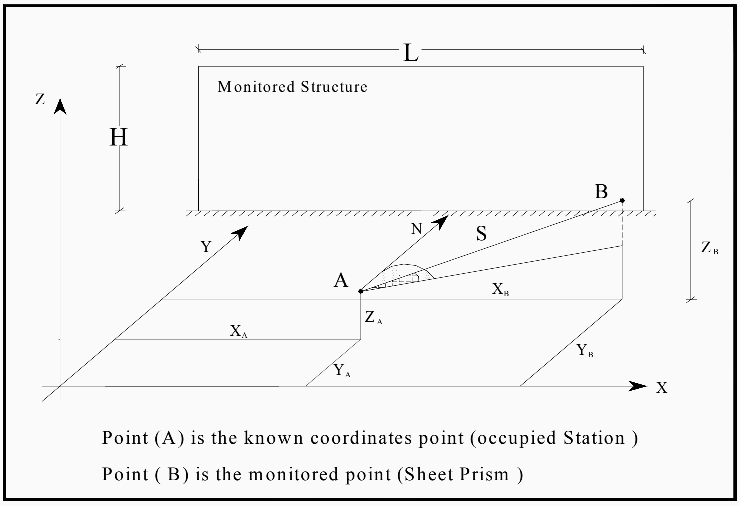

Figure 1. The geometry of one total station technique

2.2 Two total station technique

The two total stations technique employees the intersection process in three dimensions to determine the spatial coordinates of a specific target. Figure 2 illustrates the geometry of the two total stations technique. A local three-dimensional rectangular coordinates system is needed to calculate the spatial coordinates of any target points. There are two known coordinates points (XA, YA, ZA) and (XC, YC, ZC). From these two known points (A and C), we can determine the coordinates of unknown point B. From figure 2, there are three unknowns (XB, YB, ZB) and six observations (slope distances S1, S2, horizontal angles α1, α2 and vertical angles γ1, γ2). Then the least squares estimation (LSE) adjustment technique will be used to calculate the coordinates of point (B) and its accuracy.

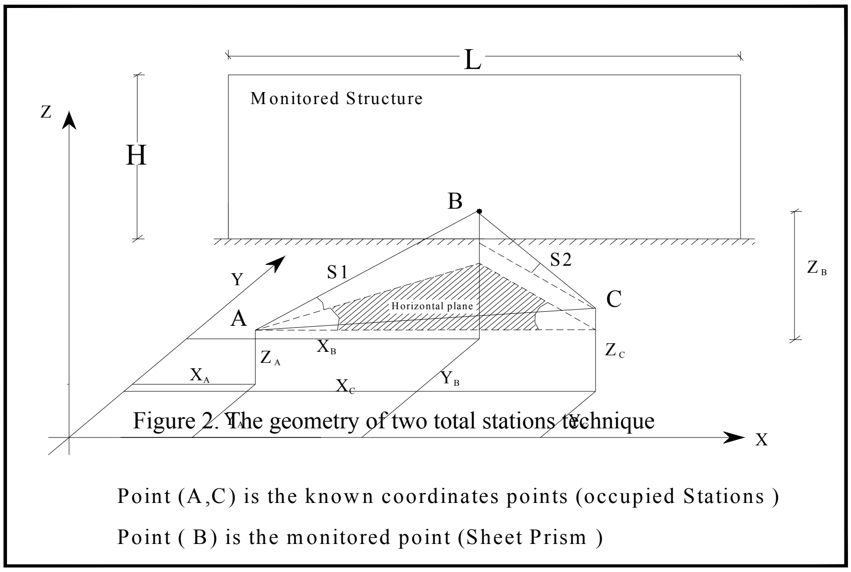

Figure 2. The geometry of two total stations technique

3. BEAM DEFLECTION ANALYSIS

A beam which is subjected to loading will bend into an arc which can be defined by a curvature function [9]. The equation, known as the governing differential equation for the elastic curve, is shown in equation 1. It is a second-order linear differential equation and is composed of the beam's bending moment, M, which is a function of x, the distance along the beam, divided by the modulus of elasticity, E, and moment of inertia, I. The bending moment is a reaction to an applied force which causes a structure to rotate or bend. This equation holds true for small deflections. Integrating equation 1 twice, with respect to x, will yield the function of deflection. This function will permit the vertical deflections to be computed.

$$\frac{\partial^2 z}{\partial x^2} = \frac{M\ (x)}{EI} \tag{1}$$

For the case in this paper, a simply supported beam (i.e. a support point at each of its ends) consisting of a load point, P, at the centre of the beam, located at X_P. A sketch is shown in Figure 3.

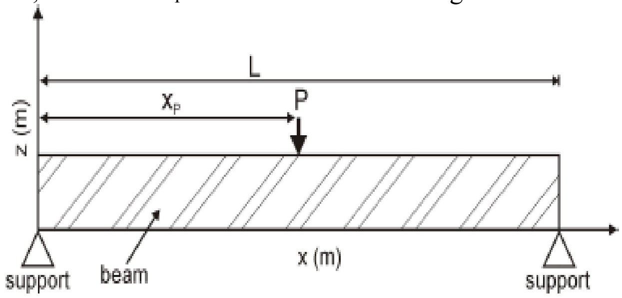

Figure 3. Schematic diagram for the beam

The bending moment, represented by two functions (one each side of X_P), is linear, maximum at X_P and zero at each support point. Two successive integrations yield a cubic equation. An accurate value for high strength beam deformations is needed, hence a flexible surveying technique is needed to overcome the obstacles of using strain gauges and dial gauges, and make the process of measurements easier and more accurate.

4. STRUCTURAL DATA ANALYSIS

Structural analysis is required to determine whether significant movements are occurred between the monitoring campaigns. Geometric modeling is used to analyze spatial displacements. General movement trends are described using a sufficient number of discrete point displacements (dn):

dn (Δx, Δy, Δz) for n = point number

Point displacements are calculated by differencing the adjusted coordinates for the most recent survey campaign (f), from the coordinates obtained at reference time (i). Each movement vector has magnitude and direction expressed as point displacement coordinate differences. These vectors describe the displacement field over a given time interval. Comparison of the magnitude of the calculated displacement and its associated accuracy indicates whether the reported movement is more likely due to observations error [5].

$$\left| \mathbf{dn} \right| < (\mathbf{e_n})$$

Where: $\left| \text{dn} \right|$ is the magnitude of the displacement for point n. It can be calculated as:

$$\left| \text{ dn } \right| = \sqrt{(\Delta X)^2 + (\Delta Y)^2 + (\Delta Z)^2} \tag{2}$$

and **(en)** is the maximum dimension of combined 95% confidence ellipse for point (n), it can be calculated as following:

$$e_n = 1.96 . \sqrt{(\sigma_f)^2 + (\sigma_i)^2} \quad (3)$$

Where:

σf is the standard error in position for the (final) or most recent survey, σi is the standard error in position for the (initial) or reference survey. Then

| dn | < (en) the point isn't moved.

| dn | > (en) the point is moved.

5. MONITORING OF THE VERTICAL WALL

The precision of the points that have been monitored using the discussed surveying techniques should be evaluated to study the effect of the used instrument position distances and the angle of observations on the monitoring point accuracy. To achieve that goal, the monitoring of the vertical wall is done. A mesh of twelve monitoring points on the (7.7m x 3.0m) wall is distributed for coordinating a building facade. A local three-dimensional rectangular coordinates system is needed to calculate the spatial coordinates of any target points on the mesh. Two points are selected near the wall as reference points. In each case, the coordinates of all points and its standard error are calculated.

5. 1 Observations and analysis of one total station technique results

A local three-dimensional rectangular coordinates system is needed to calculate the spatial coordinates of any target points on the mesh. Such a system, presumably, has X-axis is chosen as a horizontal line parallel to the base direction, which the Y-axis is a horizontal line perpendicular to the base direction and positive in the direction towards the object, the Z- axis is a vertical line determined by the vertical axis of the instrument. To find the best position of the used instrument and the best locations of monitoring points, some test measurements are carried out in the wall zone:

1- Reliance of the accuracy on the distance from the instrument position to the wall (D).

2- Reliance of the accuracy on the angular of line of sight.

5. 1.1 Dependence on the distance from the instrument position to the wall

In this case, the line of sight of the instrument is perpendicular to the wall but the instrument position distance (D) differs five times (D=L/2, D=3L/4, D=L, D=5L/4 and D=3L/2), Where, L is the wide of the wall. From the differences between the measurements, a statement about the accuracy is possible. Then the following notes can be deduced. For " σ_X", when the instrument position distance increases, the standard deviations of all points will decrease. For "σ_Y", when the instrument position distance increases, the standard deviations of all points will increase. For «σZ", when the horizontal angle (α) increase, the standard deviations will decrease, and when the vertical angle (γ) increases, the standard deviations will increase. The graphical representation of (D/H) ratio opposite the standard deviations is done. It is obvious that there is no optimum distance minimizes the standard deviations in three dimensions.

5.1.2 Reliance on the angular of line of sight

The importance of the angular of the line of sight to the wall is shown by scanning the profile in figure 4. In this case, the distance between the instrument position and the wall is constant. Four different stations are used. Then, it is obvious that the horizontal angle (α) has a great effect on the standard deviation in X and Y –directions but this effect is small on Z- direction. Hence, when the horizontal angle (α) close to zero, the accuracy will increase. To achieve the maximum accuracy, it is important to ensure a maximum symmetrical configuration of the monitoring points on the monitoring object.

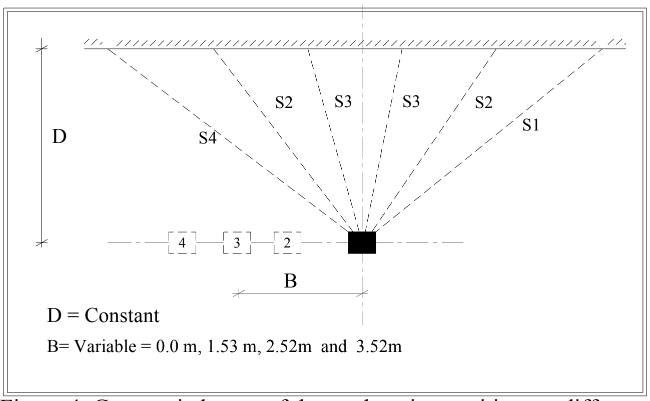

Figure 4. Geometric layout of the total station positions at different (B)

5. 2 Observations and analysis of two total stations technique results

To find the best position of the used two instruments and the best locations of the monitoring points for this technique, some test measurements are carried out in the wall zone. The distributed targets are observed from two occupied stations O1 and O2 as shown in figure 5.

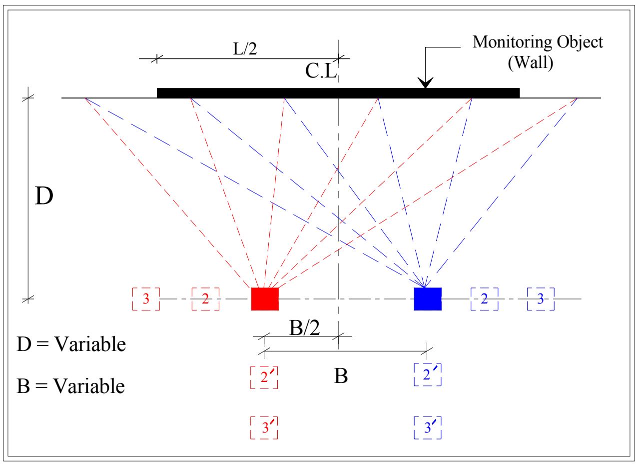

Figure 5. Geometric layout of the two total stations positions relative to the object plane of the wall

The test measurements are carried out in the wall zone for:

1. Reliance of the accuracy on the distance from the two instrument stations to the wall (D) at constant (B).
2. Reliance of the accuracy on the distance between two instruments (B) at constant (D).

Using least squares adjustment technique to calculate the adjusted coordinates and the associated accuracy for each monitoring point on the wall. The graphical representation of standard deviations opposite to the distance between the two instruments (B) is done as following in figures 6, 7.

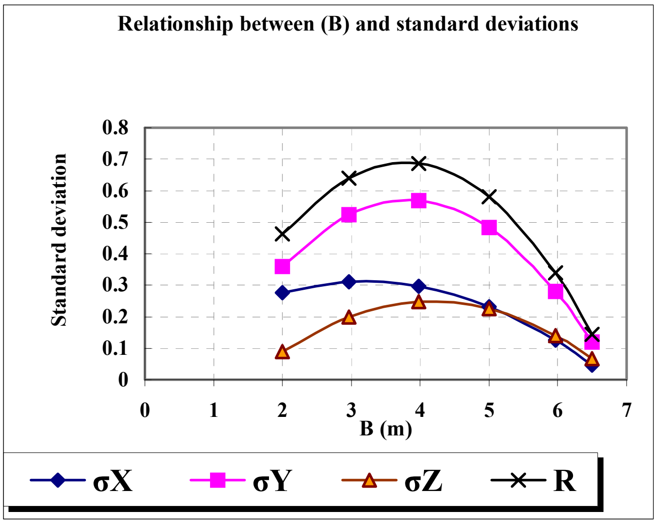

Figure 6. The relationship between the two instruments distance (B) and the standard deviations

The best distance (B0) between the two instruments can be graphically determined according to that R must be minimum, this value relative to the façade building have been determined as:

B0 = 0.7545 L

The graphical representation of standard deviations opposite to the distance (D) between the two instruments and the wall is done. The best distance (D0) between the two instruments and the monitoring wall can be graphically determined, this value relative to the façade building have been determined as:

D0 = 0.242 L

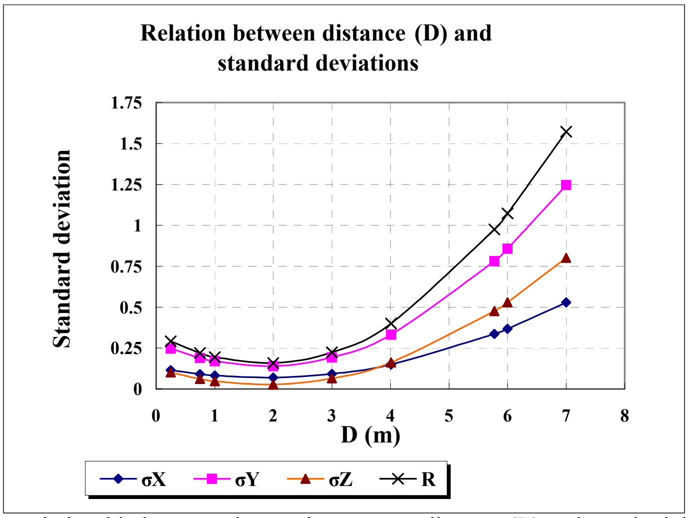

Figure 7. The relationship between the two instruments distance (D) and standard deviations

6. THE BEAM DEFORMATION MONITORING

The structural application consists of four reinforced concrete beams, to estimate the deformation of these beams subjected to specified loads. The four tested beams have the same section (225 cm*20 cm*12 cm), but differ in reinforcement as shown in figure 8. Two of them have 2Φ12 and the others have 2Φ16. The steel used is high mild steel. The beams also have 5Ø6/m/ as stirrups. High Strength Concrete (HSC) mix is used. Ordinary Portland cement and natural sand with high fineness modulus of 2.65 and Coarse aggregate (natural gravel) with a maximum of 12 mm are used. Powder silica fume with SiO_2 of 92%, specific gravity of 2.2 and specific surface area of 16.8

m2/g is used. High Range Water Reducers (HRWR) superplasticizers with trade name (Conplast 430) are used to improve both fresh and hardened concrete properties [8]. The proposed mix is shown in table1

C	Ms/C	W/(C+Ms)	PZ	PZ/C	S	G/(S+G)	fc7	fc28
Kg/m3	%		Type	%	Kg/m3		MPa	MPa
450	7	0.25	Conplast 430	3	650	0.65	415	61

Where: C= Cement Ms= Micro silica

PZ= Superplasticizer S=Sand G= Gravel

fc7, 28= 7, 28 days Cube Compressive Strength.

Table1. Composition of High Strength Concrete and selective mixture and Cube Compressive Strength

Two total stations (NIKON DTM 850 and SOKKIA SET300), sheet prisms of diameter 1cm and calibrated dial and strain gauges are used in the field measurements. The rate of loading is 0.35 ton beginning at unload case to reach the failure load at 4.20 ton as shown the experimental beam in figure 9.

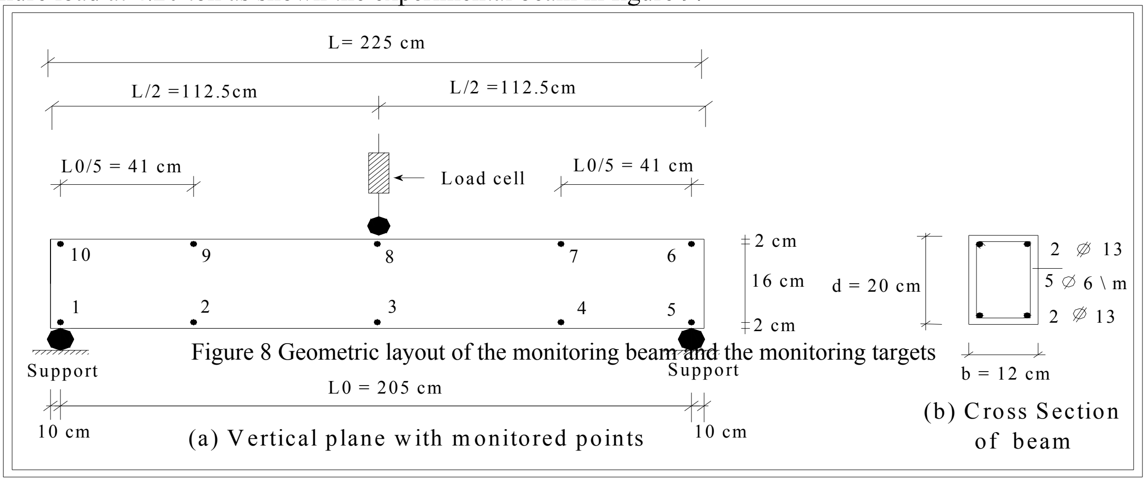

Figure 8 Geometric layout of the monitoring beam and the monitoring targets

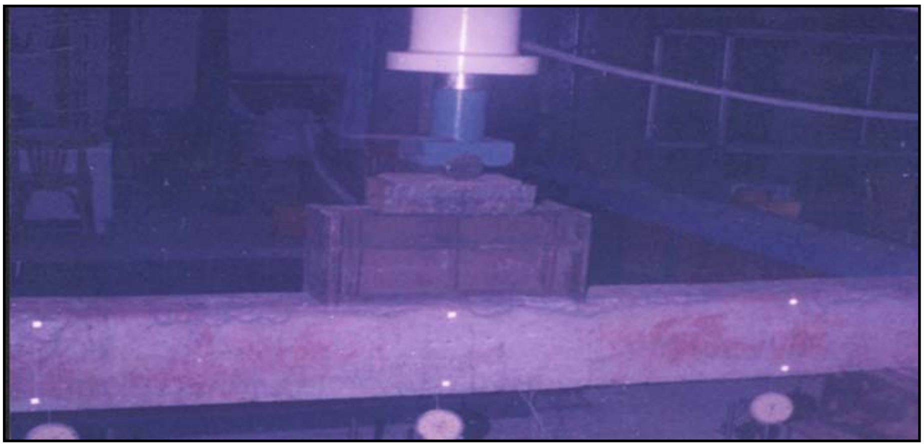

Figure 9. The tested beam with the concentrated load and prisms

The important and vital results are displayed in the following:

6.1 Analysis of one total station observations

This beam is tested by using the one total station technique. The beam face is divided into ten monitoring points. The spatial distribution of these points should provide complete coverage of the beam as shown in figure (8). The selected monitoring points are located where the maximum deformations have been predicted such as points (3 and

8), plus a few points which is depending on previous experience could signal any potential unpredictable behavior such points (1, 2,4,5,6,7,9 and 10). These points are located by using sheet prisms of diameter (1cm), which are arranged to be visible from the location of the used total station as shown in figure 6.

The adjusted vertical displacements of ten monitoring points under all cases of loading are calculated. A Comparison between the deflection values from one total station technique and dial gauge readings is done. The resulted deflection values from the one total station analysis are very close to those obtained from dial gauge readings. The differences between the two techniques are too small. By using the same structural analysis technique, the adjusted displacements in X- direction can be calculated. The displacements in X-direction for upper raw of monitoring points (6, 7, 8, 9 and 10) are greater than the lower raw of monitoring points (1, 2, 3, 4 and 5). The maximum displacement value at point 10 and load 4.2 ton, and this value is 6.93mm. The directions of point's displacements in X and Z-direction at failure load can be graphically shown in figure 10.

By using the same structural analysis technique, the adjusted displacements in Y- direction can be calculated. It is obvious that no movement in Y- direction occurs. Then, the final deformed shape of the monitoring beam at failure stage can be drawn as shown in figure 10.

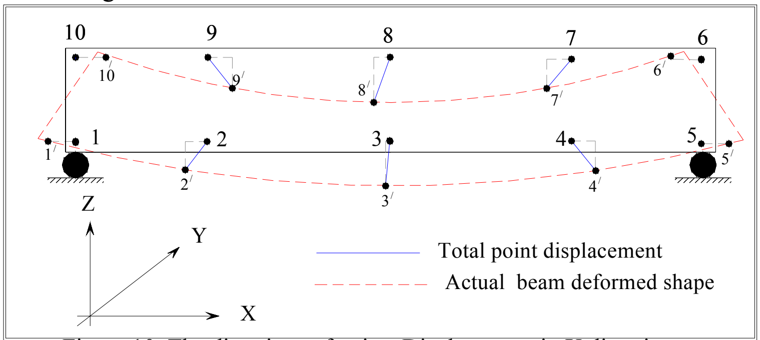

Figure 10. The directions of points Displacement in X direction

6.2 Analysis of two total stations observations

The last beam is tested by using the two total stations technique. The beam face is divided into five monitoring points as shown in figure 11. The spatial distribution of these points should provide complete coverage of the beam. The adjusted coordinates and its associated accuracy of each point in the monitoring network are calculated by using MathCAD program and least squares adjustment technique.

A comparison between the deflection values obtained from the two total stations technique and dial gauge readings is done. It is obvious that the deflection values from the two total stations technique are very close to dial gauge readings from p= 0.35 ton to load p=3.85 ton. After load p=3.85 ton, there is a clear difference because of the vibrations of dial gauge during loading especially the dial gauges are placed under the tested beam.

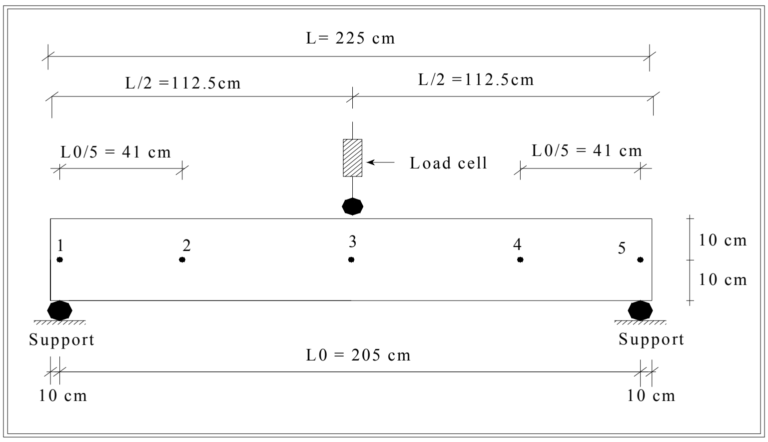

Figure 11. Geometric layout of the monitoring beam points for the two total stations observations

8. CONCLUSION

The results of experimental work lead to the following conclusions:

1. The two used surveying techniques (one total station and two total stations) can provide valuable data on the deflection of the structural members and movement of buildings because the resulted deflection values from surveying techniques with the discussed adjustment techniques are very close to the values from dial gauge readings.
2. The accuracy of the monitoring target coordinates is improved if the two total stations are set in the site at their best locations instead of using one total station. The best parameters were determined graphically:

B0 = 0.7545 L   **D0 = 0.242 L**

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