Movement detection on a concrete structure during traffic flow using Global Positioning System

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Abstract. Global Positioning System (GPS) monitoring has been interested in a sensing technology of the structural responses to monitor the movement of a concrete bridge because basic data are obtained by field measurements. Two stations as a base station with a long observation situated at the embankment of the bridge. The establishment stations observation has been cover from morning until night. This paper explores the possibility movement of Sultan Idris Shah Bridge structure using static signals to enhance the measurement of total static movement response of a bridge structure. The results are shows with the two epochs actual movement motions generated by the motion of real work. The determination of movement of measuring points installed on the bridge is dividing into two times frame namely peak and non-peak hour. Those of error ellipse explain relationship between movement and traffic flow. The largest ellipse was register at non-peak hour. This is caused by the low volume of traffic flow in which average speed of vehicle at this period of time is about 50-60km/h. The analysis of the bridge movements, the current operational safety, the cause of bridge cracks, sensitivity of GPS signals, and its movements were observed under traffic loads. The comparative results demonstrate that the proposed technique can significantly enhance the measurement of the total movement of a structure.

1. Introduction

Expected cost of maintenance and initial bridge costs will increase significantly due to changes in joints and bearings required by design movements too large. Modular expansion joints are selected by engineers from sealing strips or compression joints with a range of more than 4 or 5 inches (100 to 125 mm). If the movement is greater than 2.0 inches (± 50 mm) then the sliding pedal loop is used and if small movements can be used elastomer pads [8]. In-situ method is important when studying the bridge movement to detect the vibration or deflection of the bridge which usually does not exceed millimeters. Hence reducing the cost of infrastructure recovery and saving time in identifying bridge problems. [7]. Therefore, the detection of concrete bridge movements can be obtained by reference to vehicle movement using GPS technology. In the field of Civil Engineering, monitoring of different infrastructures is always an important issue. Transportation infrastructures get some special concern among them especially transportation network is Bridge [15]. Bridges built using concrete are the most widely used building materials for their compressive strength. Characteristics such as permeability, ductility, frozen-resistance, resistance, abrasion resistance, reactivity and strength can be determined [6].
1.1 Innovative in detecting bridge structure movement.
Given the recent technological advancements, GPS has the potential to be utilized in high-accuracy/high-precision monitoring of bridge movement. Few records have been found indicating prior testing of GPS as a viable option for bridge movement monitoring. In addition, little background information currently exists detailing the configurations that may optimize the accuracy and precision of GPS data collection [9]. Bridges are important infrastructure considering its use and purpose serving. Bridge may fail due to different loading conditions. It may be due to some permanent loads like dead load, earth and water pressures. There also exist occasional loads like earthquake forces, vehicle live load, wind forces etc. Deformations may occur due to creep shrinkage and settlement. So, all combination of those or independent cases can be the crucial part for damage of structure [4]. The automated measurement system (AMS) can monitor the state of the bridge structure in the long run where several innovative technologies are applied in determining the dynamic deformation of the bridge structure [q]. AMS can consist of technologies such as total station, GNSS and geotechnical equipment. Therefore, more instrumentation is needed to study reliability, and durability of bridges to provide more information about bridge condition [5].

1.2 Geometrical monitoring of structural
There are two groups in geometric monitoring to detect structural deformations [1]; Geodetic measurement and measurement of geotechnical structures. In the use of survey engineering, especially the deformation monitoring of GPS usage structure is preferred as the points on the structure are monitored with precision up to centimetres in real time. [3]. GPS is a widely used application and provides high accuracy and weather-friendly observations. The value of all coordinates of GPS observations (Xs,Ys and Zs) is converted in the form of three-dimensional geocentric coordinates associated with (Xe,Ye and Ze). Measurement of angles and distances is a common method of giving adequate observation advantages for statistical assessment in detecting errors [2] and [11]. Appropriate use of equipment is necessary in measuring and monitoring the deformation of each structure as progress in technology is evolving.

Figure 1. Sultan Idris Shah bridge, cross the Kinta River.
2. Observation sites and the proposed geodetic monitoring technique

Research area are Sultan Idris Shah Bridge (GPS: 4.59813, 101.07925) is one of the two main bridges across the Kinta River that separates Ipoh Old Town from Ipoh New Town. Sultan Idris Shah Bridge was built in 1907 and has been upgraded a few times. Sultan Idris Shah Bridge has been chosen for the purpose of the movement monitoring study. This bridge was suited in Ipoh city. This city is the capital of Perak governorate in Malaysia and located in the middle of the Kinta River. The studied highway bridge connects Old Town and New Town (Figure 1), has a total length around 100 m and a width 17 m with average height 7.55 m above ground level. The main objective of the planned network is to provide several stations with relative and absolute positions. The monitoring of the proposed bridge structure consists of a small horizontal geodetic network on the left and right of the bridge marked on the bridge. Well known, this bridge has four lanes in one direction. The bridge over the age of 20 is constructed of reinforced concrete including sponge made of steel. From the overall, the bridge is supported by four pillars and two abutments. The observation of geodetic network was carrying out at the first epoch of monitoring observations in April 2017. Site reconnaissance and topographic surveying of the bridge area were done before starting the process of first observation epoch for the bridge monitoring. All stations of geodetic networks were fixed in stable positions on the bridge. Each point of the studied bridge contained 9 monitoring points. By using more reference stations by JUPEM is necessary, the points are placed and arranged with reference to the beams and marked safely.

3. Traffic flow count on the studied bridge

It is dependent on the environmental condition and operation if the data collected from the monitoring indicates that the static response of the bridge may change [12]. Some of the direct response from the structure may affect the physical parameters and the bridge mechanisms are due to the linkages such as ambient temperature, wind speed and direction, humidity, sun rays and vehicle loading. The Inertia effect were ignored to the impact of a vehicle on a bridge is assumed from the moving. Also the impact on the strength and serviceability of bridge which has being significant to the live load due to the daily traffic [13]. However, the inertia effect on bridges can be consider as a moving mass for the vehicles. In this paper, traffic flow count was performed in the peak and not-peak hours of the studied bridge at Figure 2(a), 2(b), 3(a) and 3(b). The different value of coordinate flow from traffic count in the five epochs of observations are presented in Table 1.

![Figure 2(a)](image1.jpg) The traffic flow on the peak hours. Around 7:00am–10:00am and 1:00pm–3:00pm

![Figure 2(b)](image2.jpg) The traffic flow on the peak hours. Around 5:30 pm–6:45 pm
Figure 3(a). The traffic flow on the not-peak hours. Around at 3:00 pm – 5:00 pm.
Figure 3(b). The traffic flow on the not-peak hours. Around at 10:00 am-1:00 pm.

Table 1. The monitoring points according to Time Frame (TF) of peak and not-peak hours

| Hours     | Time Frame | Time       | Hours     | Time Frame | Time       |
|-----------|------------|------------|-----------|------------|------------|
| Peak      | 7:00-10:00 am | A          | Not-Peak | 10:00 am-1:00 pm | D          |
|           | 1:00-3:00 pm  | B          |          | 3:00-5:30 pm   | E          |
|           | 5:30-6:45 pm  | C          |          |             |            |

The bridge monitoring was carried out according to the following procedure:

- In the first epoch of observations (April 2017), the coordinates were determined from GPS observations. Then the horizontal geodetic network was fixed on stable positions.
- The adjusted coordinates of all stations of network were then determined and the most probable values were then calculated for all observations using least squares adjustment (conditional method).
- The monitoring points were observed (9 points) which 15 minutes each. Then the coordinates of all points were calculated applying the mathematical model presented for each epoch of observations.
- The values of deformation due to the coordinates of reference stations must be checked to have the same coordinates. Small deviations between these coordinate as mentioned in Table 1. The parameters transformation was applied to remove these deviations for all observation epochs.
- The analysis of observations was done and the resulted new coordinates of monitoring points after applying transformation parameters be performing.

Few factors such as acceleration or deceleration, number of vehicles, vehicle type combination and driver’s behaviour due to lane-changing which is the evolution of traffic flow to complete [14]. Simple analysis was done to indicate the relationship between time frame and traffic volume. The duration of measuring was more than 10 hours (from 7:00 am to 8.00 pm).

4. Results and discussion
Determination of deformations of measuring points installed on the bridge is divided into 2 times of period namely peak and not-peak hour. Peak hour referred to 3 periods; 7am-10am, 1pm-3pm and 5.30-6.45pm while non-peak time referred to 2 periods; 10am-1pm and 3pm-5.30pm. Refer to Table 2, the coordinates of measuring points were determined in local coordinate system. Measured of the observed point are in figure 4(a) and 4(b). Those size of ellipse explain relationship between deformation and traffic flow. The largest ellipse was
registered at non-peak time. This is caused by the low volume of traffic flow in which average speed of vehicle at this period of time is about 60-70km/h.

Figure 4(a). An elliptical error on the first epoch on March 30th, 2017

Figure 4(b). An elliptical error on the second epoch on March 31st, 2017

Table 2. The summary of each analysis of the movement of geodetic coordinates of the monitoring points in two epochs.

| No. | Date      | Time Frame          | Categories (hour) | Findings                                                                                     | Ellipse shape |
|-----|-----------|---------------------|-------------------|----------------------------------------------------------------------------------------------|--------------|
| 1   | 30/3/2017 | 5.30pm-6.45pm       | Peak              | Movement conditions are almost identical to point B1. 1E starts at peak time.                | Small        |
| 2   | 30/3/2017 | 1.00pm-3.00pm       | Peak              | Point difference 3C to 31/3 TF B where the elliptical error is the same. Traffic time in slow state and less displacement takes place. | Small        |
| 3   | 30/3/2017 | 7.00am-10.00am      | Peak              | The ellipse situation is less movement due to slow traffic.                                 | Small        |
| 4   | 30/3/2017 | 5.30pm-6.45pm       | Peak              | Movement larger than 3A and 1E because 3A and 1E are on embankment. Point 3B is aligned with bridge beams. (At peak time, the size of the ellipse at the point being parallel to the beam is large). | Medium       |
| 5   | 30/3/2017 | 5.30pm-6.45pm       | Peak              | The same movement with 1E.                                                                  | Small        |
| 6   | 31/3/2017 | 7.00am-10.00am      | Peak              | Movement is not much.                                                                        | Small        |
| 7   | 31/3/2017 | 7.00am-10.00am      | Peak              | Traffic jam.                                                                                | Small        |
| 8   | 31/3/2017 | 5.30pm-6.45pm       | Peak              | Traffic jam.                                                                                | Medium       |
| 9   | 30/3/2017 | 3.00pm-5.30pm       | Non peak          | Non peak time and vehicle speed 60-70km / h. Ellipses on this point are huge.              | Big          |
| 10  | 30/3/2017 | 3.00pm-5.30pm       | Non peak          | Great reading on major axes. Shift on traffic routes.                                       | Oval         |
| 11  | 31/3/2017 | 10.00am-1.00pm      | Non peak          | Big error.                                                                                  | Medium       |
| 12  | 31/3/2017 | 10.00am-1.00pm      | Non peak          | Speedy traffic                                                                               | Medium       |
| 13  | 31/3/2017 | 3.00pm-5.30pm       | Non peak          | Speedy traffic                                                                               | Big          |
The adjusted coordinates and its associated accuracy of each point in the monitoring network on the bridge for all epochs was calculated using the least square adjustment technique. The weather situation for the observations made on the 30th was hot weather compared to the 31st, which was heavy rain in the afternoon. This allows the assumption of change as a result of fast stream flow being contributors to movement. Small changes at peak hour due to various vehicle speeds such as school buses because the bridge is locating near to a school. Numerous cars, trucks, vans and motorcycles are stuck due to traffic congestion on top of the bridge. This happens when it is less movement of the vehicle on the bridge. This reduces the tremor on the bridges indirectly. On the other hand, when it is not peak hour, the vehicle is in a less crowded and speedy state. Indirectly, the tremors become strong as the last vehicle over the bridge is at a speed of nearly 70km/h. The prediction of the bridge resonance is not directly affected by the span length during the critical vehicle speed. Based on scientific studies, for a continuous bridge with the same length for each range, the critical speed for the first resonance takes place is the same and no middle-range resonance occurs for second mode, either in the vertical and radius. The first and last range exhibits similar displacement patterns, both within dimensions and lesser terms [10]. This does not happen to short bridges and no extension of the span as well as the movement on the bridge takes place clearly. The detection of monitoring point’s movement is coming from the field observing, measurements and adjustment techniques of the network. The values of movement for bridge structure is computed using the statistical test using Chi-Square Test with a confidence level of 98%.

5. Conclusions
The geodetic monitoring technique can provide of the valuable data movement for the structure such as bridges. Those of error ellipse explain relationship between movement and traffic flow. The largest ellipse was registered at non-peak hour. This is caused by the low volume of traffic flow in which average speed of vehicle at this period of time is about 50-60km/h. The comparative results demonstrate that the proposed technique can significantly enhance the measurement of the total movement of a bridge. From the GPS monitoring and analysis observations, it can be seen that the bridge movement components in static components are safe under existing loads. The bridges are studied with respect to serviceability limit states only using GPS. The purpose is to study the bridge movement which may reflect excessive deflection, vibration and cracks on bridge. This can be concluding that more equipment is needed to study the reliability and durability of bridges such as strain gauges, accelerometers, tilt meter and others which provide more information about bridge condition.

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