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Monitoring of Displacements on Suspension Bridges using GPS

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Summary

It is proposed in this paper a new measurement method using GPS to measure semi-static and long period movements of suspension bridge girders. The field measurements on dynamic movements were carried out using this system on the Hakucho suspension bridge during the strong wind season, and semi-static displacements of girders were successfully obtained and agreed well with numerically predicted values. Spectral analyses were conducted for the displacement data collected both by GPS and by accelerometers as well, which show good agreement in the frequencies between 0.1 to 0.4Hz. This is also confirmed by the numerical results calculated by FEM bridge model and forced vibration tests. This method is therefore proved to be useful for dynamic measurements of semi-static and ultra-long period movements of long-span bridge girders.

1. Introduction to GPS Monitoring System

The monitoring system on dynamic behaviors has been installed on major suspension bridges in Japan to assure the safety of vehicles and structures. However, vibration periods are very long on long-span suspension bridges and there exist both semi-static and periodic movements in lateral directions due to wind forces, therefore, the conventional measurement system with accelerometers are unable to catch these movements. It is proposed in this paper a new monitoring system using GPS (Global Positioning System) which utilizes electric waves from satellites to measure semi-static and long-period movements of suspension bridge girders.

The Hakucho Bridge is a suspension road bridge with main-span of 720m and two side-spans of 330m each. The girder is a streamlined steel box girder with width of 23.0m and maximum web height of 2.5m. The bridge crosses the Muroran Bay and suffers strong winds during typhoon and winter seasons. As a part of extensive dynamic tests conducted on the Hakucyo Bridge, field measurements using GPS were carried out for three weeks in March 1998 just before the bridge opened for vehicles in June.

The real-time monitoring of 'kinematic GPS' was used in this measurement. Two sets of GPS antennas and receivers were placed at mid-span of the girder and at the office on land with distance in between about 1 km. Both antennas simultaneously received electric waves from several satellites, and the displacements of three directions, vertical, lateral and longitudinal, were obtained by the phase difference of both waves. A pair of telemetry links between the main and reference receivers were installed, and the measured data were analyzed by a processing software run on a laptop PC. Sampling time was 1.0sec.

Before the field measurement, a test was carried out to evaluate errors caused by this GPS system. The main antenna was temporarily fixed on the tower base, and forced to move 10cm in three directions and measured. It showed that the error was within 1.6 cm in the lateral and longitudinal directions and within 0.5 cm in the vertical direction.

2. Measurement Results and Spectral Analyses

A typical record measured from 1:00 a.m. to 7:00 a.m. on March 1998 showed longitudinal displacements Dx, lateral displacements Dy, vertical displacements Dz, wind speed U and wind angle Ur. The wind data was obtained by a ultrasonic anemometer on the tower top. Dominant wind direction Ur was WNW-NW, which was slightly diverted from the girder transverse angle W. The wind speed U varied between 5m/s to 20m/s in this data.

Lateral displacements Dy consisted of both semi-static components and fluctuating components. The semi-static displacements varied with wind speed U and there is strong correlation between Dy and U. The maximum Dy reached about 20cm when wind speed is about 20m/s, which agreed with the wind tunnel test results. Vertical displacements Dz and longitudinal displacements Dx consisted of only fluctuating components, and there seemed no correlation on Dx and Dy against U.

The data were divided into two minute data, and the relation of averaged Dy versus lateral components of wind speed Uy were compared with the theoretical values. These values were predicted by three dimensional FEM using drag coefficients C_D of 0.75 for girders and 0.70 for cables, which were obtained by the wind tunnel tests. The measured data Dy agreed very well with the numerically predicted values.

The girder displaces up and down because of the temperature change of the main cables, and the vertical displacements Dz measured for 24 hours clearly showed this periodic movements. The measured displacement range in the day was nearly equal to the calculation based on the maximum temperature change measured by the thermometer installed inside of the cable.

The data were analyzed by Fourier transform. Fourier spectrum of Dx, Dy and Dz showed clear frequency peaks. Accelerometers were also placed at the same position of GPS antenna and the acceleration data was collected at the same time. Peak frequencies obtained by GPS data and those obtained by accelerometers agreed very well. The bridge was later forced to vibrate by exciters and natural frequencies were obtained. The peak frequencies obtained by GPS agreed well with these natural frequencies and also with those calculated by three dimensional Finite Element bridge model. This proves that GPS method is reliable for dynamic measurements of ultra-long period movements in lower frequency range.

3. Conclusions

A new measurement method using GPS was applied to measure displacements of suspension bridge girders. Field measurements were carried out using this system on the Hakucho Bridge during the strong wind season. This study proves that GPS method is efficient for measurements of semi-static and long period movements of long-span suspension bridge girders. During stormy weather, it is difficult to judge only by wind data when a bridge should be closed for vehicles. However, monitoring girder displacements by GPS can give useful and appropriate information for the judgement. This monitoring system also helps us to find structural abnormal phenomena in early stages, and consequently contributes to long-term durability of structures.