Smart Structures and Systems, Vol. 6, No. 1 (2010)

Technical Note

DOI: http://dx.doi.org/10.12989/sss.2010.6.1.087
Smart Structures and Systems, Vol. 6, No. 1 (2010) 87-90

Technical Note

Structural health monitoring of the Manitoba Golden Boy

Bogdan A. Bogdanovic[1], Ashutosh Bagchi[2]* and Aftab A. Mufti[3]

[1]*Crosier Kilgour Partners. Ltd. Structural, Winnipeg, Canada*
[2]*Dept of Building, Civil & Envir. Eng., Concordia University, Montreal, Canada*
[3]*ISIS Canada Network, University of Manitoba, Winnipeg, Canada*

(Received June 5, 2008, Accepted July 24, 2009)

1. Introduction

The Golden Boy Statue as shown in Fig. 1 was installed on top of the Manitoba Legislative building in Winnipeg, Canada in 1919 (Mufti 2003). During an inspection in 2001, the support shaft of the Golden Boy was found to be severely damaged due to corrosion in the steel shaft that supported the statue (Fig. 2) which was then replaced by a stronger stainless steel shaft. In addition, a range of sensors including accelerometers, strain sensors, thermocouples, wind meter, and video camera were installed for monitoring the structural condition of the shaft (ISIS 2009). Structural Health Monitoring (SHM) technique is a powerful tool evaluating the in-situ performance of a structure (Mufti 2003; Liu 2008; Bagchi, *et al.* 2007). This paper presents the key elements of the SHM system for the Golden Boy including processing and interpretation of the SHM data. The orientation of the instruments on the stainless steel shaft is shown in Fig. 3. The overall scheme of the sensor data acquisition and transfer is shown in Fig. 4.

2. Analysis of monitoring data

2.1. Mechanical model of the shaft

The Golden Boy sculpture is hollow and it is attached at two locations: (i) near the bottom, directly above the plate and below the Golden Boy's left heel, and (ii) at the top of the stainless steel shaft which terminates at the torso height. The support shaft is modeled as a simple cantilever with a lumped mass at the top as the hollow shell is found to provide no significant structure rigidity (Mufti 2003). Based on the actual length of the shaft and the bent at the bottom, the length of the equivalent cantilever is calculated to be 2.75 m and constant cross-sectional diameter of 140 mm (5.5 inches).

2.2. Strain data

The direction of wind on the Golden Boy is predominantly in the north-south (N-S) direction. The highest wind (gust) of speed 59 Km/hr occurs on September 24, 2003 and March 10, 2004, and the strain data from the south face after thermal strain correction on September 24, 2003 are as shown in Fig. 5. Strain history calculated from the wind analysis is shown in Fig. 6.

*Corresonding Author, E-mail: abagchi@bcee.concordia.ca

Fig. 1 The golden boy statue

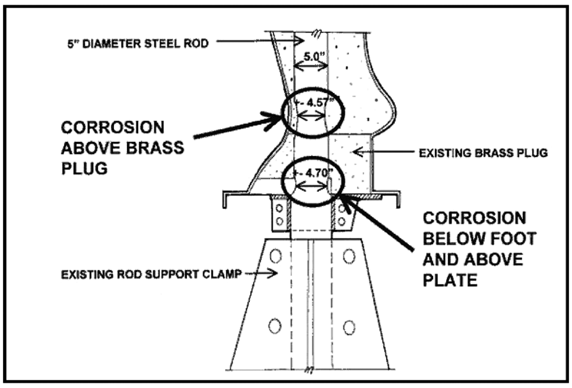

Fig. 2 The corroded shaft

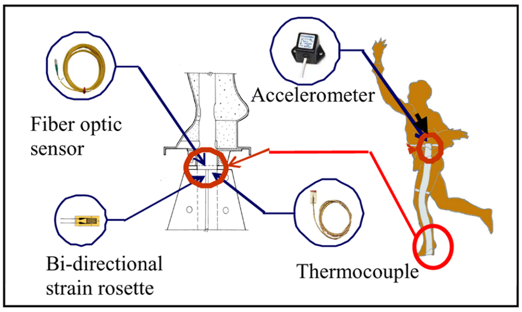

Fig. 3 Instrument locations

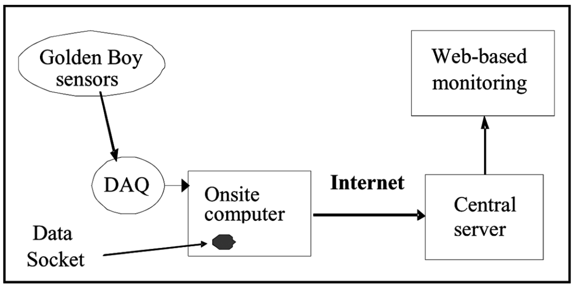

Fig. 4 Data transfer scheme

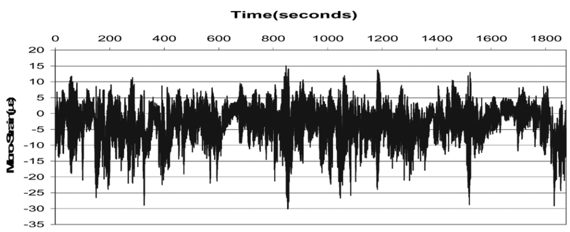

Fig. 5 Strain gauge data (South) on September 24, 2003

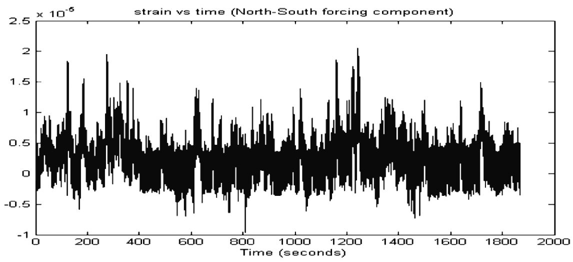

Fig. 6 Strain form the dynamic analysis

2.3. Accelerometer data

For the cantilever model of the shaft, the lumped mass at the top was determined to be 1575 kg, and the theoretical natural frequency of the structure works out to be 2.95 Hz. Fig. 7 shows the Y-direction accelerometer data (acceleration in g's) and the Fast Fourier Transform (FFT) of the corresponding signal in Fig. 8. The fundamental frequency of the Golden Boy shaft as observed from Fig. 8 is 3 Hz, and over the ten month period of the study (from September, 2003 to May, 2004) and in recent months, it is observed to be within a steady range of 3.05 Hz. to 2.95Hz.

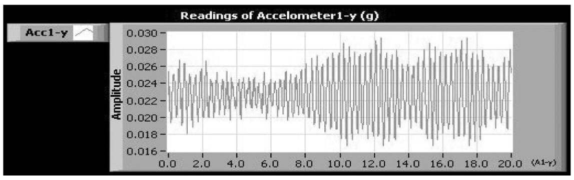

Fig. 7 Typical accelerometer data

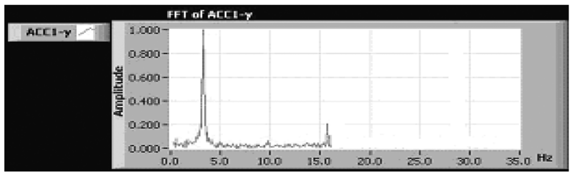

Fig. 8 FFT of the accelerometer data

Table 1 Comparison of wind velocity and strain

DATE	Maximum velocity(km/hr)			Peak strain values		
	Wind meter	Environment Canada {Peak hourly velocity)	Correlated wind speed at the roof top	Strain gauge analysis ($\mu\varepsilon_s$)	Wind meter analysis ($\mu\varepsilon_w$)	$\frac{\mu\varepsilon_w}{\mu\varepsilon_s}$
September 24, 2003	62	59	72	31	21	0.68
March 10, 2004	70	59	72	30.5	38	1.25
January 21, 2004	70	54	62	27	33	1.22
January 2, 2004	135	50	60	30.5	150	4.91
October 27, 2003	54	43	51	15.3	18	1.18
October 22, 2003	50	43	51	16.9	17.5	1.04
November 20, 2003	50	43	51	14	9.9	0.71

2.4. Wind meter data

The wind data is converted into external pressure by using the wind loading provisions of the National Building Code of Canada (NBCC 1995). An approximate projection area of the statue calculated at 15 degree interval (starting with the north face) as shown in Fig. 9 is used for estimating the wind forces in different directions. The strain response on a highly windy day due to the N-S component of wind forces is shown in Fig. 6. Considering the 100 year wind, the maximum longitudinal stress due to the combined loads (ie, dead load and wind load) is found to be close to 94 MPa, which is much lower than the yield stress of steel.

2.5. Discussion on the results

Table 1 shows some of the dates for which the data from the Golden Boy's SHM system have been analyzed for the periods when the peak wind speed is recorded. The hourly peak wind speed as reported

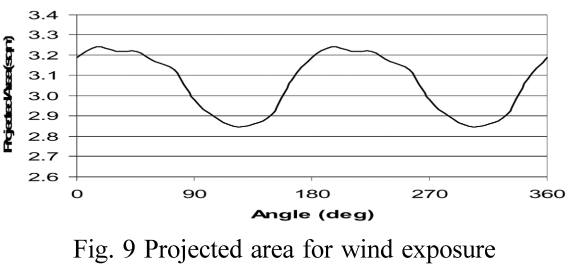

Fig. 9 Projected area for wind exposure

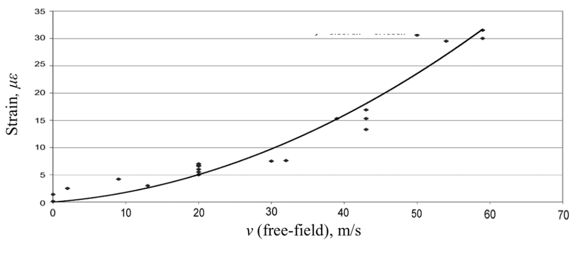

Fig. 10 Max strain vs. hourly free-field wind velocity

by Environment Canada (EC 2008) based on the measurement at Winnipeg Airport, is also reported for comparison. The strain gauge analysis and dynamic analysis results are compared, and they are found to be within approximately 10 $\mu\varepsilon$ with the exception of January 2, 2004 which is exceptionally high, perhaps due to malfunctioning of the wind meter at that time. Regression analysis is used here to establish the relationship between the strain and the free-field wind velocities (i.e., wind speed recorded at Winnipeg airport) as shown in Fig. 10.

3. Conclusions

The study indicates that the range of wind speeds of 59-50 Km/hr produces the maximum strain values of approximately 30 $\mu\varepsilon$. This relates to a wind-induced stress of 6 MPa and the combined stress of 94 MPa at the base of the shaft, which are fairly low. The observed value of the fundamental frequency ranges from 3.05 hertz to 2.95 hertz, while the theoretical value is 2.95 Hz. The simplified empirical relationship presented in Fig. 10 is a useful tool to the owner of the structure to get an estimate of the strain in the shaft based on the free-field peak wind velocity.

Acknowledgement

The authors acknowledge the support of ISIS Canada Research Network and the Natural Sciences and Engineering Research Council (NSERC).

References

Bagchi, A., Humar, J. and Noman, A. (2007), "Development of a finite element system for vibration based damage identification in structures", *J. Appl. Sci.*, **7**(17), 2404-2413.

EC (2008), http://www.ec.gc.ca/weather, Official web site of Environment Canada.

ISIS (2009), http://www.isiscanada.com, Official web site for ISIS Canada Research Network.

Liu, S.C. (2008), "Sensors, smart structure technology and steel structures", *Smart Struct. Syst.*, **4**(5), 517-530.

Mufti, A.A. (2003), "Restoration and structural health monitoring of manitoba's golden boy", *Can. J. Civil Eng.*, **30**, 1123-1132.

NBCC (1995), National Building Code of Canada, National Research Council of Canada, Ottawa.

CC