Numerical simulation of bridge deformation based on real-time ground displacement monitoring data

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1. Introduction

Landslide is the most important and frequent natural calamities that cause severe socio-economic and human losses. However, to facilitate the transportation of people in remote areas, many road constructions extend to mountainous areas where landslide would occur, and the conditions of these structures cannot be inspected frequently. Many structures show the varying degrees of damages due to landslide each year. Therefore, to keep the structures from the damage of landslide remains a crucial and urgent task of engineering, especially in those remote and mountainous areas.

To maintain the serviceability of the structures cost-effectively and to keep the structures from the threat of landslide, this paper deals with the Global Navigation Satellite System (GNSS). The GNSS is one of the real-time monitoring methods that has been widely used for the structural health monitoring of different structures in the past two decades [1].

The GNSS has been applied to monitor the ground displacement caused by landslide near the bridge site. First, the landslide-caused bridge displacement data are used to build a numerical model, and then the agreement between the actual deformation and the simulated results is discussed.

2. Bridge Profile

The target bridge, located in Hokkaido, is a non-composite double-H-shaped steel plate girder bridge with 40.5 m long and 4.7 m wide. It was built in 1966. The longitudinal profile of the bridge is shown in Figure 1.

The terrain interpretation map is shown in Figure 2. According to the survey report of this bridge, the sliding block indicated in the figure has pushed the bridge at abutment A1, which causes the longitudinal deformation of the bridge.

3. Monitoring of Bridge Behavior

To confirm the impact of landslides on the bridge, two GNSS monitoring points have been installed near abutments A1 and A2 in which horizontal displacements have been measured every hour. In addition, strain gauges were glued on the lower flange of G1 girder of the bridge to measure its longitudinal strain. Figure 3 shows the positions of the GNSS monitoring points (red dots) and the strain gauges (blue dots).

Figure 4 shows the measured strain and displacement with a regression line. The strain of -136 μ was recorded at the horizontal displacement of 6 mm. The fluctuation in measured strain data would be caused by temperature changes.

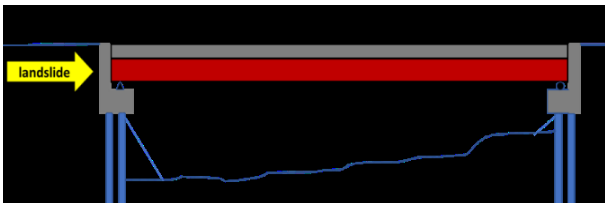

Figure 1 Longitudinal profile of the bridge

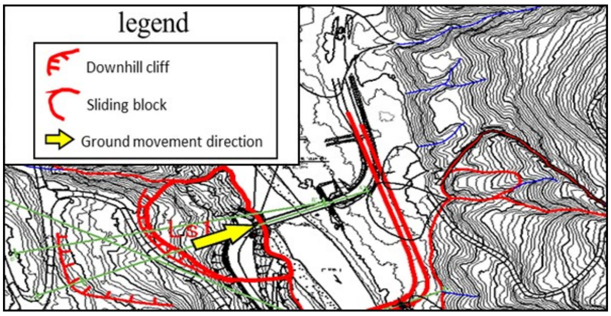

Figure 2 Terrain interpretation map

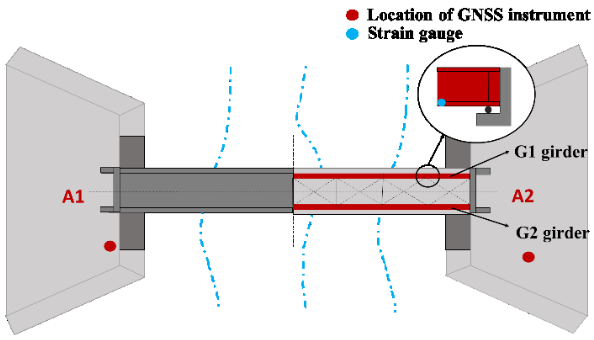

Figure 3 Locations of the monitoring instrumentation

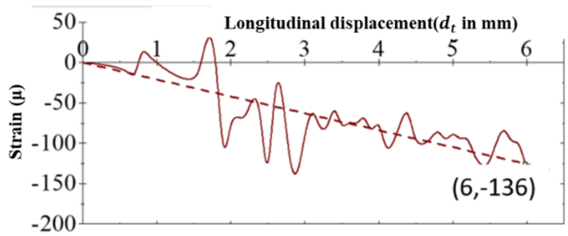

Figure 4 Strain-displacement data at the strain gauge point

4. Numerical Simulation

Non-linear finite element analysis was carried out. The material properties used in this analysis are given in Table 1. For the constitutive law of the materials, the Hordijk tensile softening model and the CEB-FIP 1990 compression model [2] was used for concrete, and the von Mises plastic yield model [3] was used for steel.

Table 1 Material properties

	Concrete	Steel	Rebar
Young's modulus (GPa)	25.5	200	210
Density (kg/m^3)	2340	7860	7860
Poisson coefficient	0.2	0.3	0.3
Yield strength (MPa)	-	325	295
Comp strength (MPa)	25	-	-
Tensile strength (MPa)	2.2	570	440

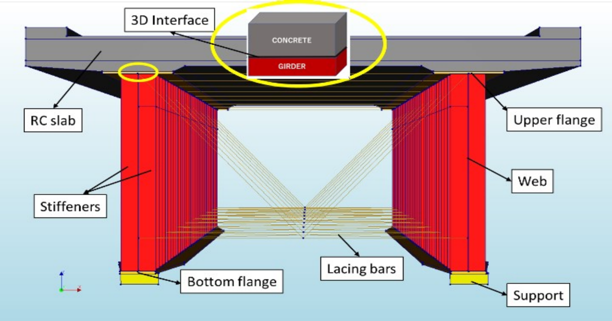

Figure 5 Bridge model

Longitudinal displacement (d_t) was applied for the analysis. It was assumed that the displacement by the GNSS is consistent with the displacement applied to the bridge at abutment A1.

Figure 5 shows the analysis model of the bridge (cross sectional view). The two steel girders were simplified as shell elements, assuming that movable connections between the concrete slab and the upper flange of the girder. A 3D friction interface between the concrete slab and the upper flange of the girders was defined by using the Coulomb friction interface with the cohesion of 0 and the friction coefficient of 0.40.

5. Analytical Results and Discussions

The relationship between d_t and longitudinal strain of the girder is shown in Figure 6. The relationship can be divided into three segments. Segment I is defined when d_t is between 0 to the 4.3 mm, in which the strain increases almost linearly as increase in d_t. The measured and analyzed results agree well. Segment II is defined when d_t is between 4.3 to 6.0 mm. The strain increases with increase in d_t, and the analytical results become slightly larger than the measured results. The measured strain is -136 μ when d_t equals to 6.0 mm, while the analytical result is -146.1 μ. From the segments I and II, the measured and analytical results show good agreement.

When d_t reached 6.0 mm, remedial measures were taken to release the strain. To understand the behavior of the girder without the remedial measures, increase in the strain was predicted, which is indicated in Segment III in the figure.

Figure 7 (1) shows the widths of cracks of the RC slab at d_t of 40 mm. The slab started cracking near abutment A2. Figure 7 (2) shows the width of cracks at d_t of 60 mm. Additional cracks are found near the midspan and abutment A1 as well. Accordingly, the landslide causes uplift of the bridge slab to induce flexural moment. Cracks near abutment A2 are more significant than those near A1 as indicated in the red circles.

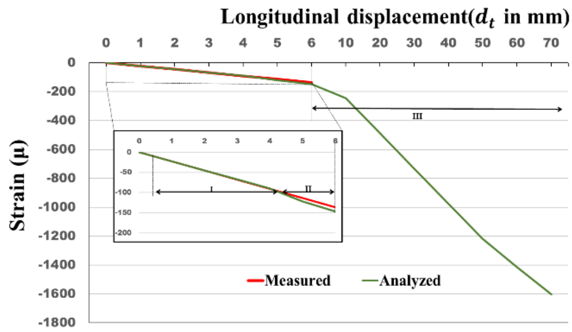

Figure 6 Relationship between d_t and strain

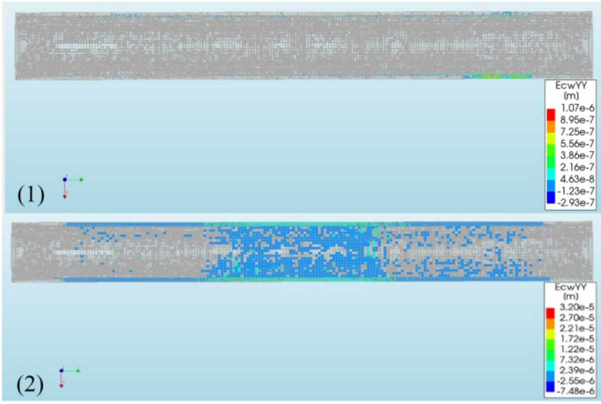

Figure 7 Widths of cracks at (1) d_t=40 mm and (2) d_t=60 mm

6. Conclusions

The following conclusions were drawn:

(1) When the longitudinal displacement is smaller than 4.3 mm, the measured and the analytical results agree well. When the displacement is between 4.2 and 6.0 mm, the difference between the measured and the analytical results starts to appear: about 5% difference at the displacement of 6.0 mm.

(2) The model in this paper is reasonable to preliminarily understand the safety of the bridge suffering from landslide.

The research is hoped to provide a simulation process of the bridge deformation caused by landslide and to offer assistance for the subsequent maintenance management. Besides, feedback is expected to obtain to optimize the performance of the established model.

References

[1] Chen Q, Ju B, Xi R, Meng X, Jiang W and Fan W. 2017. GNSS for Real-time Monitoring of Bridge Dynamic Responses. *Forum on Cooperative Positioning and Service* (CPGPS), DOI: 10.1109/CPGPS.2017.8075121

[2] Hsu MC, Kida T, Abe T, Sawano T and Ozawa Y. 2019. Deformation of RC Slabs under the Static-Load. http://www.cit.nihon-u.ac.jp/kouendata/No.39/3_doboku /3-048.pdf, viwed on 29 October 2019.

[3] Kuratani M, Nemoto Y, Soma Y, Terada K. 2016. 3D fracture simulation of reinforced concrete based on fracture mechanics for concrete and its performance assessment. *Transactions of JSCES*, Paper No. 2016004.