Introduction of Chapter7 & 8 of ACECC Monitoring Guideline

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Outline

1. [Chapter 7] Monitoring of Slopes
2. [Chapter 8] Monitoring of Cable-stayed Bridges

[Chapter 7] Contents

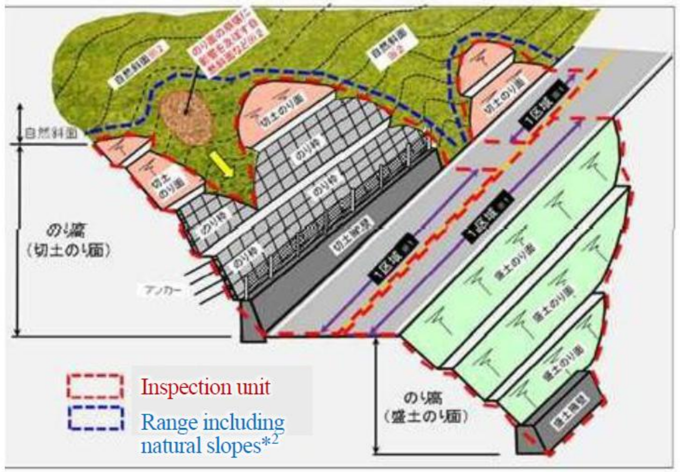
7.1.1 Target Hazards and Structures

- **Target Hazards:**
  Collapses(relatively small-scale rapid slope deformations), Landslides(large-scale slow-moving) and Rockfalls
- **Target Structures:**
  Cut, Fill and Natural slopes

Although the slope protection facilities (shotcrete mortar, retaining walls, reinforced soil walls, ground anchors, etc.) described in the figures are covered by the Guidelines for the Inspection of Road Earthwork Structures, they are not included.

Road landslide disaster

- **collapse**
  - Slope collapse
    - Any soil slope
      - Erosion/collapse
      - surface collapse
      - Large scale failure/Landslide failure
    - embankment slope
      - rock collapse
      - Shallow embankment failure
      - Deep embankment failure
      - Collapse including foundation ground
  - slope failure
    - Erosion-collapse
    - surface collapse
    - Large scale failure/Landslide failure
    - Rock collapse
- **Falling rock**
  - Falling type (Rolling stone type) Falling rock
  - Peeling type (Floating stone type) Falling rock
  - others
- **Slippery**
  - landslide
  - Slip
  - landslide
  - landslide
- **debris flow**



(Partially modified from Road Earthworks: Guidelines for Cut and Slope Stabilization Work (FY2009 Edition))

Figure 7.1.1 Classification of slope landslides (Partially modified from Road Earthworks: Guidelines for Cut and Slope Stabilization Work[1])

Figure 7.1.2 Earthwork structure of the targeted slope (Extracted from 2)

7.1.3 Screening for Slope Monitoring

- **Since the number of slopes is enormous, it is advisable to first narrow down the targets for monitoring based on qualitative judgments using existing inspection data and so on.**

<Points>

- **A) Slope failures are often caused by rainfall. Small-scale slope failures are influenced by the intensity of rainfall over time, while large-scale failures are dominated by cumulative rainfall.**
- **B) Slope failures often occur within five years after the completion of earthwork structures.**
- **C) Statistically, cut slopes experience twice as many failures as embankment slopes. Out of 2,360 recorded disasters, 47% involved cut slopes, and another 47% involved embankment slopes. Natural slopes account for only 3%, but the volume of soil involved is massive.**
- **D) Cut slope disasters occur at a rate of 2 per 10 km of road length, while embankment slope disasters occur at a rate of 1 per 10 km.**
- **E) 90% of cut slope disasters involve surface soil discharges, most of which occur within a depth of 1 m and up to 3 m in most cases. Embankment slope disasters often result from a combination of materials (e.g., masa, shirasu, mudstone) and topography (e.g., water catchment, girdling).**
- **F) Cut slope disasters significantly impact mainline traffic, causing problems in 20% of all cases. Additionally, drainage structures are involved in about 50% of cut and fill slope disaster cases.**

7.2.2 Installation of Monitoring Technology

- **The advantages of monitoring technologies over visual inspections and existing dynamic observations are different for each technology but can be summarized as follows.**

<Points>

- **A) Enable measurement under conditions that make on-site inspections difficult (e.g., remote locations, severe winter, high altitude, nighttime, stormy weather)**
- **B) Allow remote and real-time monitoring of local conditions**
- **C) Allow continuous monitoring through fixed-point observations (accumulating deformation data on individual slopes)**
- **D) Provide quantitative understanding and prediction of slope stability based on engineering thresholds**
- **E) Capable of capturing slope deformations from an areal viewpoint, even when the extent of the deformations is unclear**
- **F) Use inexpensive and simple measuring devices that are maintenance-free (no need for replacement)**
- **G) Applicable without special knowledge of measurement planning, equipment placement, or evaluation of results**

7.3.2 Implementation Examples (1)

Constant monitoring of unstable rock masses using rockfall hazard vibration survey method

<Purpose>

- The stability of unstable rock masses with the potential for rockfall is quantitatively and continuously monitored to determine the need for and timing of actions.

<Overview>

- The rockfall hazard vibration survey method was used to constantly monitor a 2×2-meter rock mass on a 30-degree slope along a national highway in Nagano Prefecture. This area has rocks that require countermeasures according to the disaster-prevention chart. This rock mass is at a high elevation and difficult to access in winter due to snow, making it useful for assisting inspections.

<Management benefits>

- The stability of the rock mass could be determined quantitatively, allowing for measures such as traffic restrictions. The monitoring system, using communication equipment, enabled constant remote observation of the rock mass’s stability without needing personnel on-site, even in winter when access is difficult due to snow.

Figure 7.3.1 Equipment Installation Status

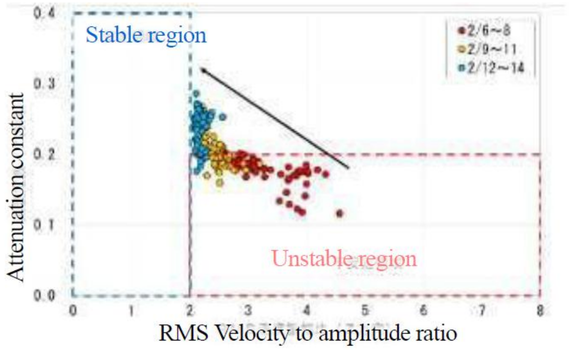


Figure 7.3.2 Example of Hazard Assessment Diagram

7.3.2 Implementation Examples (2)

Monitoring slope stability using multi-point inclination displacement and soil moisture

<Purpose>

- Monitor slope deformation during emergencies (disasters) to ensure traffic safety, implement traffic restrictions, monitor countermeasure works, prevent secondary disasters, and ensure safety during restoration work.

<Overview>

- A roadside cut slope collapsed due to rainfall from a typhoon. Six inclination sensors were installed on the collapsed soil to ensure the safety of the restoration work. Subsequent rainfall caused a secondary collapse, and the tiltmeter K-2 in the center of the slope collapsed. Just before tipping, the inclination sensor showed accelerated creep failure behavior.

<Management benefits>

- 1) Real-time, quantitative understanding of the stability of the collapsed slope through constant monitoring of multi-point tilt displacement and soil moisture; 2) Clarification of measures such as traffic safety and controls after disasters, and prevention of secondary disasters through safety monitoring during countermeasure works (collapse alarms were sent to the site and used for evacuation measures).

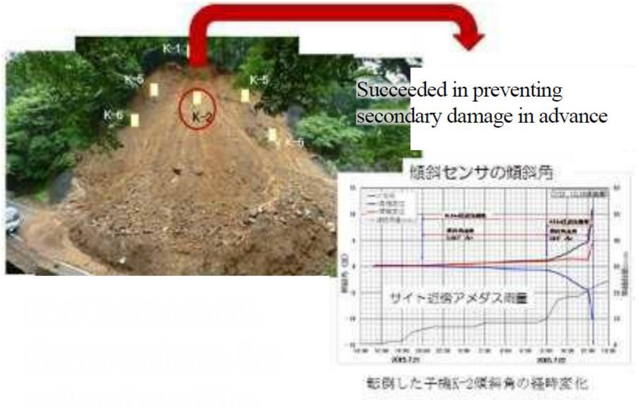


Figure 7.3.9 Equipment Installation Locations on the Cut Slope of the Damaged Road

Figure 7.3.10 Photo After Damage to the Cut Slope of the Road

[Chapter 8] Contents

8.1.1 Positioning

- **Target Structures:**
  Stay cables of suspension bridges, cable-stayed bridges, or extradosed bridges etc.

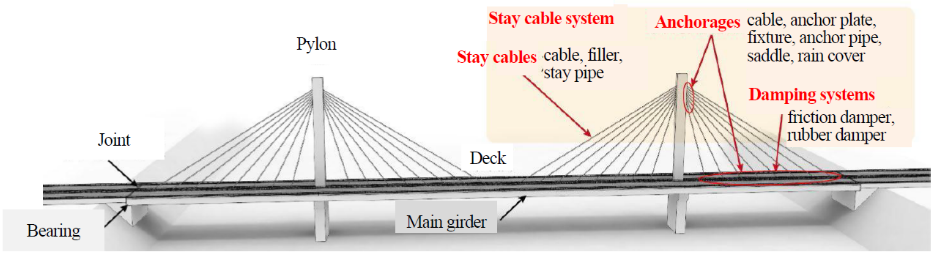


Figure 8.1.1 Configuration of a cable-stayed bridge

Table 8.1.1 Components of cable-stayed systems

System	Component	Materials
Cable-stayed systems	Stay cables	Cables (PC steel wire, PC steel stranded wire)
		Filler
		Stay pipes
	Anchorages	Cable (PC steel wire, PC steel stranded wire)
		Fixing fixture
		Anchor pipe
		Anchor plate on main girder side
		Anchor plate on tower side
		Saddle
		Rain cover
	Damping systems	Friction damper
		High-damping rubber damper

Table 8.1.2 Expected deformations in the components of cable-stayed systems

Component	Expected deformations
Stay cables	Cable rupture, corrosion, fatigue cracks, corrosion or cracks in protective tubes, vibrations
Anchorages (concrete)	Corrosion of fixtures, cracks near fixtures, delamination/exposed rebar, water leakage/efflorescence, floating
Anchorages (steel)	Corrosion of fixtures, deformation and buckling near fixtures, coating deterioration and corrosion, water leakage and stagnation, fatigue cracks
Others	Deformation of vibration dampers, leakage of filler

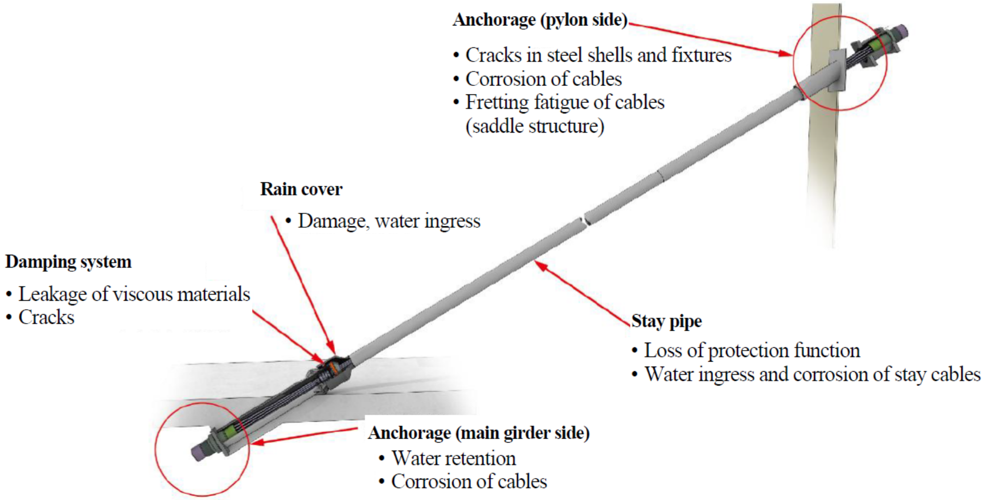


Figure 8.1.2 Focal points for inspection and investigation of cable-stayed systems

8.1.2 Types of Monitoring

- **The effective monitoring of cable-stayed bridges involves several sophisticated techniques, each contributing layers of insight into the stay cables' health.**

<Highlighted techniques>

- **Higher-order Vibration Method:**
  - **This method focuses on capturing and analyzing the natural vibrational frequencies of the cables, which are sensitive indicators of changes in tension. As load conditions or material properties evolve, the frequencies at which cables naturally resonate can shift. Utilizing sensors placed along the cables, this method allows for continuous monitoring.**
- **Eddy Current Testing:**
  - **This technique leverages electromagnetic fields to detect surface and subsurface flaws within the cables, providing detailed information on their structural integrity.**
- **Ultrasonic Testing:**
  - **Ultrasonic Testing (UT) is pivotal for detecting internal defects within the cables that surface methods might miss. This technique employs high-frequency sound waves, which are transmitted into the cable material. Any reflections of these waves, caused by internal imperfections such as cracks or voids, are captured and analyzed.**

8.3.2 Implementation Examples

- **This section describes a case study of tension monitoring by the higher-order vibration method at the Meiko Higashi Ohashi Bridge, which is a bridge currently in service of Central Nippon Expressway Company Limited. The bridge length is 700m.**

2) Target span

Figure 8.3.2 shows the spans subject to monitoring in this case study. Accelerometers were installed on the stay cables at the innermost (C13) and outermost (C24) edges.

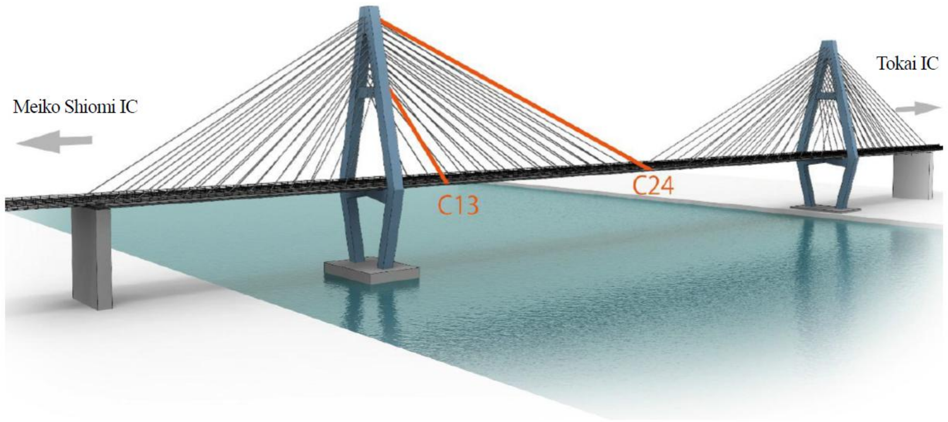


Figure 8.3.2 Target span

3) Measurement conditions

The natural frequency was calculated from the acceleration data measured under the conditions shown in Table 8.3.2, and the tension was estimated from the natural frequency.

Table 8.3.2 Measurement conditions

Items	Values
Data type	Acceleration
Number of measurements	4 times a day
Measurement time	5 minutes per measurement
Measurement axis	3-axes (X, Y and Z)
Sampling frequency	125 Hz
Implementation period	From December 16, 2019 (ongoing as of August 2020)

8.3.2 Implementation Examples

- In tension monitoring for three months or longer, there were fluctuations of a few percent, and anomalous values were sometimes detected, as indicated by the red circles.
- Although the difference between the minimum and maximum temperatures was about 25°C, the tension estimation results did not vary significantly, so it is assumed that temperature changes have little effect on the monitoring of tension changes.

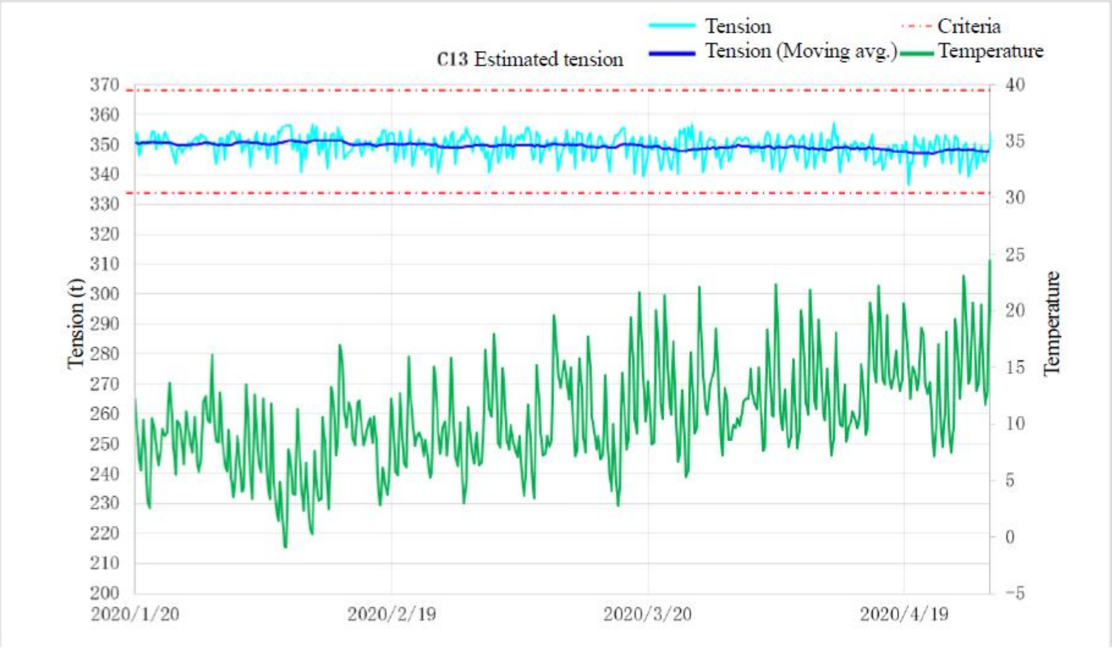


Figure 8.3.5 Estimated tension at C13

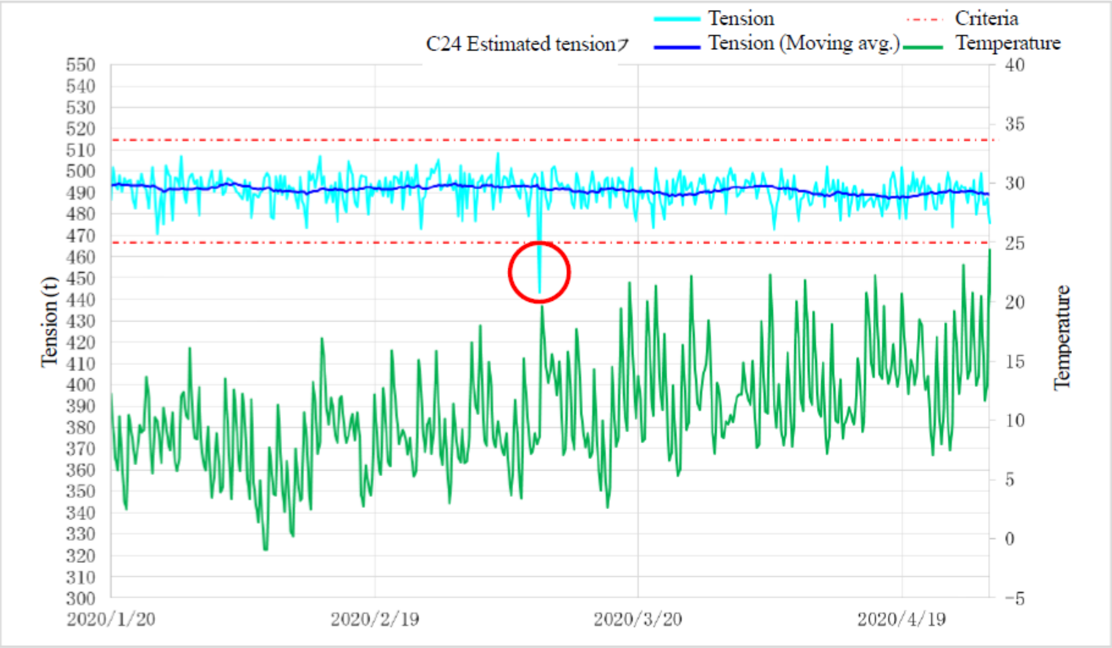


Figure 8.3.6 Estimated tension at C24

8.4 Future Directions and Innovations

<Integration of Advanced Technologies>

- Automated data analysis: Machine learning algorithms can process vast amounts of data, identifying patterns and anomalies that may indicate structural concerns. This allows for more nuanced assessments and predictions compared to traditional methods.
- Predictive maintenance: AI can facilitate predictive maintenance by analyzing trends and forecasting potential failures. This proactive approach enables infrastructure road administrators to address issues before they affect the bridge’s functionality or safety.
- Continuous improvement: As technology advances, these systems learn more effectively from data, continually improving their accuracy and the timeliness of alerts.

<Innovations in Sensor Technology>

- Enhanced sensitivity and durability: New sensor materials and designs offer increased sensitivity, providing more accurate data even under extreme environmental conditions. These innovations ensure that sensors deliver robust and reliable performance.
- IoT Integration: Sensors now increasingly form part of a broader Internet of Things (IoT) ecosystem, enabling connectivity across infrastructure assets. Real-time data communication and easier integration with smart city initiatives result in smarter, more efficient monitoring systems.