EXPERIMENTAL STUDY ON THERMAL RUPTURE OF A TENSIONING STAY CABLE ELEMENT

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1. INTRODUCTION

Fire incidents in cable-stayed bridges has been reported over the last decade, namely those of Mezcala Bridge (2007) and Chi Shi Bridge (2014). In such events, due to the thermal effect, the stays were abruptly broken and the stability of the whole structures were affected. Regarding cable loss due to fire, the “Recommendations for Stay Cable Design, Testing and Installation”, issued by the Post-Tensioning Institute (USA), states that cable loss from fire is assumed to be gradual. This term can be understand that the axial stress of the thermal-affected cable will return to zero without causing any impulse impact force. This paper is to discuss and evaluate the PTI’s statement via an original thermal cable breakage experimental program.

2. METHODOLOGY

Table 1. Properties of specimen

Material	Steel Strand
Length	5960 mm
Diameter	5.2 mm
Young modulus	195 GPa
Ultimate Tensile Strength	1930 MPa
0.2% proof stress	1670 MPa

Fig. 1 Anchorage condition of the testing cable

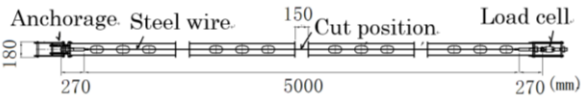

Fig. 2 Schematic of testing apparatus

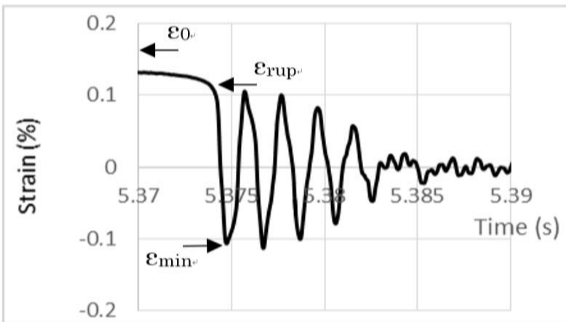

Fig. 3 Strain wave obtained from case 1, left end

This experimental program is performed on high tensile 7-wire PC strand. The material and geometrical properties of testing cable is obtained via laboratory tensile testing and is summarized in Table 1. The elastic Young’s modulus is measured as 195 GPa, the ultimate tensile strength is 1930 MPa and the 0.2% proof stress is 1670 MPa. The material properties of the specimen satisfied the PTI’s requirement. The total length of the cable is measured as 5960 mm. To maintain the similarity rule, 6 out of 7 wires are cut out, only the core wire is kept. The diameter of the core wire is 5.2 mm. Anchorage condition of the testing specimen is show in Fig. 1.
Strain gauges are pasted near the ends of each specimen to measure the longitudinal deformation of the specimen during experiment. The apparatus used in this program is a steel pipe with rear hole as shown in Fig. 2 (schematically). One end accommodates a load cell, the other end is fixed. The testing specimen is mounted into the pipe. Cutting position is the middle point of the specimen. Then, it is tensioned to simulate the real working condition of a stay in cable-stayed structure. Oxyacetylene cutting method is used to generate thermal effect and manually break the specimen at the middle position. The cutting torch can generates a flame burns at about 800-1000 ºC. The intensity of the heating flame is control to break the specimen within 2 minutes. Thermocouple is used to record the temperature near the cutting position. Sampling interval of the experimental process is 20 microseconds.

3. EXPERIMENTAL RESULT

Fig. 3 represents one example of strain wave graphs obtained from the test. The test was carried out with initial longitudinal deformation of about 0.2%. During the thermal cutting process, the strain gradually decreases from 0.16% to about 0.12% and suddenly drops to a negative peak then begins to vibrate.

Keywords: Cable-Stayed Bridge, Cable Loss from Fire, Laboratory experiment, Impact Factor
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Table 2. Experimental results

Case	IF *1*	T_{rise} *1* (ms)	ε' *1* (s^{-1})	IF *2*	T_{rise} *2* (ms)	ε' *2* (s^{-1})	f (Hz)
1	1.69	0.55	3.75	1.55	0.9	2.29	513
2	1.63	0.4	4.63	1.74	0.95	1.86	526
3	na	na	na	1.89	0.4	14.54	500
4	1.77	0.4	13.14	1.78	0.4	13.23	513
5	1.77	0.28	17.81	1.76	0.28	17.92	500
6	na	na	na	1.84	0.32	24.67	926
7	1.89	0.34	8.16	1.79	0.34	7.96	510

Observing the broken specimens explains this phenomenon (Fig. 4). Under the combined effect of pre-stress and thermal expansion, the cross section at the cutting position elongates, yields and deforms to cone shape (similar with ductility in quasi-static material test). As a result, the other parts of the specimen shorten. However, the decrease in strain is not gradual until zero, thus the PTI's statement is not appropriate in this case. Assuming that the cross sections other than the rupture one are working below the material yield strength, the impact factor (IF) can be defined by Eq. (1) as the relationship between the initial strain value (ε_0) and the value of negative peak (ε_{min}) as shown in Fig. 3.

$$IF = \frac{\Delta\varepsilon}{\varepsilon_0} = \frac{\varepsilon_0 - \varepsilon_{\min}}{\varepsilon_0} \quad (1)$$

Rising time T_{rise} is the period from the point at which the wave graph starts to drop to the point at which the wave graph registers the negative peak. In addition, the strain velocity (ε') is the rate of change in strain with respect to rising time, calculated using Eq. (2). In which, rupture strain ε_{rup} is the value when the strain graph starts to drop.

$$\varepsilon' = \frac{\varepsilon_{rup} - \varepsilon_{\min}}{T_{rise}} \quad (2)$$

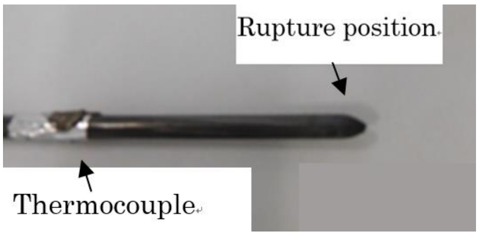

Fig. 4 Configuration at rupture position

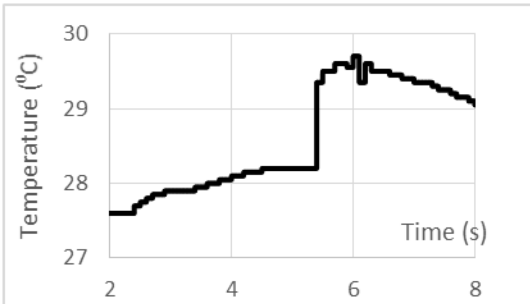

Fig. 5 Temperature near the cutting position

The post rupture vibration frequency is about 513 Hz, estimated from the strain time history graph. The summarized results are show in Table 2, in which, data obtained from the strain gauge near the left and right ends are denote as *1* and *2*, respectively. The impact factors are mostly in the range of 1.55 to 1.89. Fig. 5 show the change in temperature recorded by the thermocouple near the cutting position. Despite the cutting flame burns at over 800 ºC, it is show that the temperature increment at the nearby position is not noticeable, due to short heating time. For safety reason, impact force of 2.0 multiply with the initial axial force in the cable is recommended for this condition. There is no observable relationship between the pre-stress level and other parameters, so the initial condition is neglected from the table. The calculated rising times varies from 0.28 ms to 0.95 ms. The vibration frequencies are mostly about 500 Hz with only one exception (case 6). The obtained values are suitable with fundamental longitudinal vibration frequency of a cantilever, which can be calculated literately (Hoang et al, 2016).

4. CONCLUSIONS

This paper report an original experimental program regarding stays in cable-stayed bridges being damaged by fire. Nine steel wire under pre-stress condition were broken using oxyacetylene cutting torch. The obtained strain wave graphs showed that the stress near the anchorage of the specimen will gradually decreases and suddenly drop. There is definitely impulse impact force when a stay cable loss from fire. Therefore, the PTI's statement need complement. To assess the effect of losing stay cable due to high temperature and short heating time, impact factor of 2.0 using for the initial tensile stress acting in the anchorage was suggested. The longitudinal vibration of the broken cables were around 500 Hz, obtained by fundamental vibration theory.

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