Evaluating the cable tension results by lift-off and vibration method in Viet Nam

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Abstract. The tension force value in cable of cable stayed bridge is the importance problem and necessary to control in design and service stage. The tension force value in cable is adjusted to ensure the internal force distribution of the structure is most reasonable and to ensure the camber, deflection or general deformation of the entire bridge. This tension adjustment has been performed and verified on many normal cable-stayed bridges. The cable-stayed bridge with more than 2 towers and 3 spans which is the trend of choice in the world as well as in Vietnam with beautiful architectural styles and suitable for use in difficult or limited conditions by topography, this verification is very limited. Recently, Bach Dang cable stayed bridge with 3 towers and 4 spans has opened for service in Viet Nam in September, 2018, the authors have had the opportunity to approach the project and conduct tension measurements in cables by using the vibration analysis method at the time before project has opened for service. In order to evaluate the accuracy of the measurement results, the paper compares the results of tension force in cables that analyzed from measured by vibration method with the values of tension in cables that are directly measured by the lift-off method. These results are also compared with the results in design stage when analysing of bridge structure on software.

1. General
The cable stayed bridge with more than 2 towers and 3 continuous spans is of great interest to many researchers and has been successfully proposed in several major projects in the world such as: Millau bridge - France with 7 towers and 8 spans built in 2004, Rion-Antirion Bridge - Greece with 4 towers and 5 spans continuously built in 2004 ..., and in Vietnam such as Nhat Tan Bridge with 5 towers and 6 spans built in 201210 and Bach Dang Bridge in Hai Phong with 3 towers and 4 spans put into use in September 2018 (fig. 1).
These are new and complex structure, whose structural features are currently not fully understood [4]. Through analytical reports of some projects when researching for practical problems such as S. Arnaud, N. Matsunaga, S. Nagano & JP Ragaru, Pedro Pacheco & Filipe Magalhães, Portuguese University, 2015; Zhou-hong ZONG, Rui ZHOU, Xue-yang HUANG, Zhang-hua XIA, 2014... showed that behavior of bridge span of the continuous cable-stayed bridge has more than 2 towers and 3 spans is more different when compared with the same proposal for the normal cable stayed bridge [4].
The characteristics of this type of bridge are the reduced stiffness and complicated stress strain state [3], so that this type of structure was only used in the past when it was necessary to cross a wide river but not allowed to make too large spans due to limited architectural height such as Nhat Tan Bridge and Bach Dang Bridge in Viet Nam.
In the cable stayed bridge, cable is an important component, the tension in cable is calculated and adjusted the internal force to ensure the internal force distribution of the structure is most reasonable and to ensure the camber, deflection or general deformation of the entire bridge. The theoretical adjustment cable force values need to be verified through test measurements. Tension measurements in stay cables are necessary and very significant during both the construction and health monitoring of bridges. However, in order to assess the accuracy of the measured value, it is necessary to conduct measurements with a variety of methods.

There are many different measurement methods for determining the tension in a cable stayed up, including directly and indirectly method (the tension will be calculated through the other methods). The Cable tension can be directly measured using a load cell or a pressure meter installed at the outset of cable. The direct methods are simple with accurate results however it is so costly. The solution for this is indirect methods that develop using various responses of cable, including: strain (Kim et al, 2011), acceleration (Irvine 1981; Shimada 1994; Zui et al 1996; Russel and Lardner 1998; Kangas et al 2010; Fang and Wang 2012), ferromagnetic magneto-elasticity (Wang et al. 2005; Wang and Yim 2010), and so on [1]. Typically, the vibration method using the acceleration that developed based on the relationship between the modal properties is widely use for monitoring Bridge in practice.

This paper will present comparisons of tension force values in cable of Bach Dang 3-span and 4-span cable stayed bridges in Vietnam through 2 measurement methods: (1) is the direction measurement method (lift-off method) and (2) is a modern indirect measurement method (vibration method) when considering through the determining the natural frequencies value of the cable and thereby calculating the tension force in the cable.

2. The method to determine the Cable force of Cable stayed Bach Dang Bridge

In this study, two tension measurement methods, namely, the direct method using a small-capacity load cell (i.e., the lift-off test), the vibration method are implemented on the all cables of a 3 Pylons cable stayed Bridge, Bach Dang in Viet Nam. The tension force in cable was adjusted 2 times in construction stage, and 1 more time after construction the closed segment. After construction the close segment, all tension force in cables were determined by lift-off test. All cables are measured by using vibration test for Bach Dang bridge and presented in this paper.
2.1. Determine the cable force of Bach Dang Cable by using the lift-off method

The lift-off test is a mechanical method that uses a small-scale load cell [5], a hydraulic jack, and a displacement meter to evaluate the force in a cable (for a single wire or a stands). The purpose of a lift-off is to verify the force of a tendon or a cable after it has been stressed. A lift-off test may be required if the elongation of recently stressed tendons or cables is out of code-recommended tolerance as +/- 7%. The lift-off method can be used and in stage before the stressing tails of the tendons have been cut off.

![Figure 2. The procedure of the lift-off test [1]](image)

![Figure 3. Determine the cable force for cable stayed in Bach Dang bridge using the lift off test.](image)

2.2. Estimation the cable tension of Bach Dang Cable by using the vibration method

The vibration methods started from an inclined cable with no sag and flexural rigidity (Irvine 1981) and advanced to consider sag and/or bending stiffness to improve its accuracy and applicability (Shimada 1994; Zui et al. 1996; Russel and Lardner 1998) [1].

The vibration methods with natural frequencies measurement of cable based on the relationship between the tension (cable force) and the frequency of cable. This is the modal properties with the relationship between natural frequencies and mode shapes that the first developed as a simplified theory of Clough and Penzien 1993.

The vibration method developed by Zui et al. 1996 [2] that based on the relationship between the cable force and the natural frequency of cable with the theory and experimental results are use for analysis of this paper as following:

1. In the case of using the natural frequency of first-order mode (cable with sufficiently small sag $3 \leq \Gamma$)

$$T = 4m(f/l)^2 \left[ 1 - 2.20 \left( \frac{C}{f_1} \right) - 0.550 \left( \frac{C}{f_1} \right)^3 \right]; \quad (17 \leq \xi)$$

$$T = 4m(f/l)^2 \left[ 0.865 - 11.6 \left( \frac{C}{f_1} \right)^2 \right]; \quad (6 \leq \xi \leq 17)$$

$$T = 4m(f/l)^2 \left[ 0.828 - 10.5 \left( \frac{C}{f_1} \right)^2 \right]; \quad (0 \leq \xi \leq 6)$$

2. In the case of using the natural frequency of second-order mode (cable with relatively large sag $\Gamma \leq 3$)

$$T = 4m(f/l)^2 \left[ 1 - 2.20 \left( \frac{C}{f_1} \right) - 0.550 \left( \frac{C}{f_1} \right)^3 \right]; \quad (17 \leq \xi)$$

$$T = 4m(f/l)^2 \left[ 0.865 - 11.6 \left( \frac{C}{f_1} \right)^2 \right]; \quad (6 \leq \xi \leq 17)$$

$$T = 4m(f/l)^2 \left[ 0.828 - 10.5 \left( \frac{C}{f_1} \right)^2 \right]; \quad (0 \leq \xi \leq 6)$$
$T = 4m(f_1)^2 \left[ 1 - 4.40 \frac{C}{f_2} - 1.10 \left( \frac{C}{f_2} \right)^2 \right]; (60 \leq \xi)$

$T = 4m(f_1)^2 \left[ 1.03 - 6.33 \frac{C}{f_2} - 1.68 \left( \frac{C}{f_2} \right)^2 \right]; (17 \leq \xi \leq 60) \tag{2}$

$T = 4m(f_1)^2 \left[ 0.882 - 65 \left( \frac{C}{f_2} \right)^2 \right]; (0 \leq \xi \leq 17)$

$C = \sqrt{\frac{EI}{ml^2}}$

Where $\Gamma = \sqrt{\frac{mg}{128EA\delta^3 \cos \theta}} \left( \frac{0.31 \xi + 0.5}{0.31 \xi - 0.5} \right)$

$\delta = \frac{s}{l_0}; \frac{\xi^2}{4} = \frac{Tl^2}{EI}$

Where:
- $T$ - the tension force in cable (kG);
- $f_1, f_2$ - natural frequency in 1st-order and 2$^{nd}$-order mode (Hz);
- $W$ - weight of cable stayed per meter (kG/m);
- $L$ - length of cable (cm);
- $g$ - gravitational acceleration (981 cm/s$^2$);
- $E$ - elastic modulus of cable (kG/cm$^2$);
- $I$ - inertia bending moment of cable stayed (cm$^4$).

Detail the tension force of cables that calculated from the measured natural frequency of cable are shown in section 3.

3. Comparision the cable force from the liff-off method in Bach Dang Cable stayed Birdge in Viet Nam with that determined from analysis the vibartion of cable.

The main designed parameters of the multi – main spans cable stayed bridge for the analysis model in all three cases are as follows: The main spans (center span) has a length of 240m, side span length is 110m ($L_b/L_c = 0.458$). The cross-sectional structure of beams using reinforced concrete material is in the form of letter $\Pi$, using composite steel material. The cross section is arranged in 6 lanes with a total width of 26m. And That is H shape tower.
The cables in Bach Dang cable stayed Bridge as showed in figure 5 that total cables arranged for 3 towers and 2 planes is 144. The fan-shaped cable with 24 cables per tower on a flat surface. The cable stayed used PWS type and diameter of each strand is 15.2mm. The name of cables is shown in fig. 6 and the detail the cable area and the cable length are presented in table 1.

**Table 1. Main parameters of cable in Bach Dang Bridge [6]**

| Cable | T28 | T29 | T30 |
|-------|-----|-----|-----|
|       | Cable area | Cable length | Cable area | Cable length | Cable area | Cable length |
| CVB/CVG 1 | 34.75 cm² | 2903.0 cm | 34.75 cm² | 2883.0 cm | 34.75 cm² | 2903.0 cm |
| CVB/CVG 2 | 41.70 cm² | 3584.6 cm | 41.70 cm² | 3550.1 cm | 41.70 cm² | 3584.6 cm |
| CVB/CVG 3 | 50.04 cm² | 4334.7 cm | 50.04 cm² | 4290.1 cm | 50.04 cm² | 4334.7 cm |
| CVB/CVG 4 | 58.38 cm² | 5149.3 cm | 55.60 cm² | 5096.7 cm | 58.38 cm² | 5149.3 cm |
| CVB/CVG 5 | 63.94 cm² | 6006.9 cm | 63.94 cm² | 5948.4 cm | 63.94 cm² | 6006.9 cm |
| CVB/CVG 6 | 72.28 cm² | 6893.7 cm | 70.89 cm² | 6829.8 cm | 72.28 cm² | 6893.7 cm |
| CVB/CVG 7 | 77.84 cm² | 7799.9 cm | 77.84 cm² | 7731.7 cm | 77.84 cm² | 7799.9 cm |
| CVB/CVG 8 | 84.79 cm² | 8720.4 cm | 86.18 cm² | 8647.9 cm | 84.79 cm² | 8720.4 cm |
| CVB/CVG 9 | 93.13 cm² | 9650.7 cm | 93.13 cm² | 9574.4 cm | 93.13 cm² | 9650.7 cm |
| CVB/CVG 10 | 105.64 cm² | 10589.9 cm | 105.64 cm² | 10508.8 cm | 105.64 cm² | 10589.9 cm |
| CVB/CVG 11 | 110.42 cm² | 11298.9 cm | 110.42 cm² | 11449.0 cm | 110.42 cm² | 11298.9 cm |
| CVB/CVG 12 | 111.20 cm² | 11720.9 cm | 111.20 cm² | 12394.0 cm | 111.20 cm² | 11720.9 cm |
| CVB/CVG 13 | 34.75 cm² | 2862.5 cm | 34.75 cm² | 2883.0 cm | 34.75 cm² | 2862.5 cm |
| CVB/CVG 14 | 41.70 cm² | 3515.3 cm | 41.70 cm² | 3550.1 cm | 41.70 cm² | 3515.3 cm |
| CVB/CVG 15 | 50.04 cm² | 4245.4 cm | 50.04 cm² | 4290.1 cm | 50.04 cm² | 4245.4 cm |
| CVB/CVG 16 | 58.38 cm² | 5044.6 cm | 55.60 cm² | 5096.7 cm | 58.38 cm² | 5044.6 cm |
| CVB/CVG 17 | 63.94 cm² | 5890.7 cm | 63.94 cm² | 5948.4 cm | 63.94 cm² | 5890.7 cm |
| CVB/CVG 18 | 72.28 cm² | 6767.4 cm | 70.89 cm² | 6829.8 cm | 72.28 cm² | 6767.4 cm |
| CVB/CVG 19 | 77.84 cm² | 7665.2 cm | 77.84 cm² | 7731.7 cm | 77.84 cm² | 7665.2 cm |
| CVB/CVG 20 | 84.79 cm² | 8577.6 cm | 86.18 cm² | 8647.9 cm | 84.79 cm² | 8577.6 cm |
3.1. Comparison the cable force of Bach Dang Cable stayed Bridge when determined using lift-off method and vibration method.

Detail the tension force in all cables are showed in table 2 and compared with the tension force in cable in the same stage when design. After that the tension force in cable that determined by analysis vibration method are implemented. The tension force value in cables that calculated from the frequency vibration method as section 2.2 above will be use to compare with the value of lift-off method and designed value.

The results of testing for vibration cable [6] are compared with the theoretical analysis results as in table 2. It is easy to show that the frequency vibration of cable in upstream are similar with the designed result. However, the frequency vibration of cable in downstream are small difference with the design value. Detail as the cables at pylon T28, the difference value is about 0-7%, especially for the cable with smallest cable length near body of pylon (cable No 1 and No14). At pylon T29, the the difference value is from 0 to smaller than 5%, the smallest difference is at the cable No 17 with 4%. And at pylon T30, the difference value is 0-6%, particularly cable No 16 is 6.3%.

![Figure 7. The result of vibration test for cable No1 at Pylon T28 of Bach Dang Bridge](image)

Table 2. The natural frequency of Bach Dang cable stayed Bridge in Viet Nam

| Cable | Frequency of cable at T28 | Frequency of cable at T29 | Frequency of cable at T30 |
|-------|--------------------------|--------------------------|--------------------------|
|       | designed | Measured at downstream | designed | Measured at downstream | designed | Measured at downstream |
|       | Hz       | Hz                      | Hz      | Hz                    | Hz      | Hz                      |
| CVB 1 | 4.833    | 4.883                   | 4.635   | 4.944                 | 4.944   | 4.881                   |
| CVB 2 | 3.998    | 3.998                   | 3.905   | 4.21                  | 4.21    | 4.149                   |
| CVB 3 | 3.327    | 3.327                   | 3.296   | 3.418                 | 3.418   | 3.449                   |
| CVB 4 | 2.762    | 2.762                   | 2.838   | 2.808                 | 2.808   | 2.869                   |
| CVB 5 | 2.411    | 2.411                   | 2.381   | 2.411                 | 2.411   | 2.472                   |
| CVB 6 | 2.075    | 2.075                   | 2.075   | 2.135                 | 2.135   | 2.182                   |
| CVB 7 | 1.846    | 1.846                   | 1.831   | 1.831                 | 1.831   | 1.869                   |
| CVB 8 | 1.663    | 1.663                   | 1.648   | 1.679                 | 1.679   | 1.663                   |
| CVB 9 | 1.480    | 1.480                   | 1.464   | 1.464                 | 1.464   | 1.495                   |
| CVB 10| 1.236    | 1.236                   | 1.221   | 1.327                 | 1.327   | 1.373                   |
| CVB 11| 1.190    | 1.190                   | 1.190   | 1.19                  | 1.19    | 1.221                   |
| CVB 12| 1.129    | 1.129                   | 1.144   | 1.099                 | 1.099   | 1.114                   |
| CVB 13| 4.822    | 4.822                   | 4.792   | 5.005                 | 5.005   | 5.005                   |

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At the pylon T28, when compare the internal cable force that determined by testing and the theoretical value, the results as:

- For the vibration testing: most tension force of cables that determined indirection through the natural frequency of cable are smaller than the designed value in range 0-10% at the upstream and 0-9% at the downstream, particularly the cable No 13, 14 with the difference value is 12.3%, 11.5% at upstream and cable No 1 with the difference value is 17% at downstream.

### Table 3. The cable force of each cable at pylon T28 in Bach Dang cable stayed Bridge in Vietnam

| Cable  | The cable force at pylon T28 - upstream | The cable force at pylon T28 - downstream |
|--------|----------------------------------------|------------------------------------------|
|        | Frequency vibration method | Lift-off method | Designed by RM software | Frequency vibration method | Lift-off method | Designed by RM software |
|        | KN       | KN       | KN       | KN       | KN       | KN       |
| CVB 1  | 2195.63  | 2435    | 2385    | 1978.27  | 2385    | 2385    |
| CVB 2  | 2693.03  | 2769    | 2737    | 2569.20  | 2751    | 2737    |
| CVB 3  | 3272.49  | 3352    | 3383    | 3211.79  | 3352    | 3383    |
| CVB 4  | 3713.18  | 3898    | 3985    | 3920.33  | 3830    | 3985    |
| CVB 5  | 4217.02  | 4319    | 4416    | 4112.73  | 4379    | 4416    |
| CVB 6  | 4650.47  | 4768    | 4820    | 4650.47  | 4800    | 4820    |
| CVB 7  | 5074.37  | 5230    | 5259    | 4992.24  | 5320    | 5259    |
| CVB 8  | 5607.12  | 5911    | 5877    | 5506.42  | 5826    | 5877    |
| CVB 9  | 5974.04  | 6325    | 6204    | 5845.57  | 6365    | 6204    |
| CVB 10 | 5690.98  | 5920    | 5826    | 5553.68  | 6027    | 5826    |
| CVB 11 | 6163.30  | 6599    | 6755    | 6163.30  | 6505    | 6755    |
| CVB 12 | 6122.83  | 6840    | 6790    | 6286.61  | 6648    | 6790    |
| CVB 13 | 2081.80  | 2380    | 2374    | 2055.97  | 2443    | 2374    |
| CVB 14 | 2358.24  | 2752    | 2665    | 2710.47  | 2652    | 2665    |
| CVB 15 | 3255.21  | 3352    | 3271    | 3080.82  | 3341    | 3271    |
| CVB 16 | 3443.46  | 3868    | 3858    | 3839.82  | 3709    | 3858    |
| CVB 17 | 4263.25  | 4255    | 4250    | 4052.08  | 4421    | 4250    |
| CVB 18 | 4616.54  | 4737    | 4773    | 4352.98  | 4878    | 4773    |
| CVB 19 | 4985.94  | 5135    | 5226    | 4821.30  | 5257    | 5226    |
| CVB 20 | 5529.88  | 5850    | 5872    | 5729.25  | 5850    | 5872    |
| CVB 21 | 5790.02  | 6405    | 6397    | 5907.98  | 6271    | 6397    |
| CVB 22 | 5352.90  | 5808    | 5765    | 5550.27  | 5737    | 5765    |
| CVB 23 | 6892.42  | 7319    | 7428    | 7045.58  | 7554    | 7428    |
| CVB 24 | 6240.64  | 6614    | 6559    | 6586.00  | 6838    | 6559    |
For the lift-off testing: The tension force of most cables is similar to the designed values and smaller with the difference value as 0-3% at upstream and 0-4% at downstream. Some cables with the tension force are higher than the designed value with the difference value as 0-2.5% when compare the internal cable force that determined by vibration testing and the lift-off method testing, the results as: The tension force value of lift-off method testing is higher than that calculated from the vibration testing 0-11% at both upstream and at downstream. Particularly, the cable No13, No14, the difference value is 12.5%, 14.3% at upstream and cable No 1, No 13, the difference value is 17%, 15.8%.

Detail as in the table 3.

At the pylon T29, when compare the internal cable force that determined by testing and the theoretical value, the results as:

- For the vibration testing: most tension force of cables that determined indirectly through the natural frequency of cable are smaller than the designed value in range 0-8% at the upstream and 0-7% at the downstream, particularly the cable No1, 12, 24 with the difference value is 11.7, 11.2% at downstream.

- For the lift-off testing: The tension force of most cables is similar to the designed values and turn around the difference value as 0-5% at upstream and 0-4% at downstream. Thus, it is difference with pylon T28, the tension force at upstream is higher than that value at the downstream.

Detail as in the table 4 following:

### Table 4. The cable force of each cable at pylon T29 in Bach Dang cable stayed Bridge in Viet Nam

| Cable | Frequency vibration method | Lift-off method | Designed by RM sofware | Frequency vibration method | Lift-off method | Designed by RM sofware |
|-------|---------------------------|-----------------|--------------------------|---------------------------|-----------------|--------------------------|
| CVG1  | 2261.43                   | 2438            | 2450                     | 2163.71                   | 2368            | 2450                     |
| CVG2  | 2929.00                   | 2934            | 2823                     | 2844.74                   | 2928            | 2823                     |
| CVG3  | 3383.25                   | 3395            | 3292                     | 3444.90                   | 3380            | 3292                     |
| CVG4  | 3580.84                   | 3692            | 3657                     | 3738.11                   | 3688            | 3657                     |
| CVG5  | 4135.28                   | 4375            | 4414                     | 4347.18                   | 4352            | 4414                     |
| CVG6  | 4739.52                   | 4835            | 4634                     | 4950.49                   | 4712            | 4634                     |
| CVG7  | 4905.32                   | 5062            | 5083                     | 5111.04                   | 5001            | 5083                     |
| CVG8  | 5713.04                   | 5952            | 5798                     | 5604.67                   | 5902            | 5798                     |
| CVG9  | 6011.13                   | 6244            | 6373                     | 6268.39                   | 6328            | 6373                     |
| CVG10 | 6459.73                   | 6612            | 6839                     | 6915.34                   | 6612            | 6839                     |
| CVG11 | 6490.40                   | 6496            | 6489                     | 6832.96                   | 6408            | 6489                     |
| CVG12 | 6487.25                   | 6072            | 5997                     | 6665.55                   | 6096            | 5997                     |
| CVG13 | 2275.05                   | 2455            | 2450                     | 2275.05                   | 2518            | 2450                     |
| CVG14 | 2931.78                   | 2916            | 2823                     | 2764.40                   | 2940            | 2823                     |
when compare the internal cable force that determined by vibration testing and the lift-off method testing, the results as: The tension force value of most cable from lift-off method testing is higher than that calculated from the vibration testing 0-5.5% at upstream and 0-7% at downstream. Particularly, the cable No 1, 12, 13, No24, the difference value is 7.2%, -6.8%, 7.3%, 7.4% at upstream and 8.6%, 9.3%, 9.6%, and 8.4%.

|       | Frequency vibration method | Lift-off method | Designed by RM software |
|-------|---------------------------|----------------|-------------------------|
| CVG 15 | 3503.07                  | 3398           | 3292                    |
| CVG 16 | 3898.76                  | 3688           | 3657                    |
| CVG 17 | 4456.90                  | 4388           | 4414                    |
| CVG 18 | 4743.96                  | 4621           | 4634                    |
| CVG 19 | 4905.32                  | 5118           | 5083                    |
| CVG 20 | 5919.02                  | 5772           | 5798                    |
| CVG 21 | 6019.34                  | 6286           | 6373                    |
| CVG 22 | 6915.34                  | 6901           | 6839                    |
| CVG 23 | 6832.96                  | 6680           | 6489                    |
| CVG 24 | 6487.25                  | 6040           | 5997                    |

**Table 5.** The cable force of each cable at pylon T30 in Bach Dang cable stayed Bridge in Viet Nam

**Figure 10.** Diagram of cable force at pylon T29 - upstream

**Figure 11.** Diagram of cable force at pylon T29 - downstream

Continue investigation at the pylon T30, when compare the internal cable force that determined by testing and the theoretical value, the results as:

- For the vibration testing: most tension force of cables that determined indirection through the natural frequency of cable are smaller than the designed value in range 0-10% at both upstream and downstream, particularly the cable No10, 22, with the difference value is 15.4%, 14.1% at upstream and he cable No10, 13, 22, with the difference value is 15.4%, 13.2% 14.1% at downstream.

- For the lift-off testing: The tension force of most cables is similar to the designed values and turn around the difference value as 0-4% at both upstream and downstream.

Detail as in the table 5 following:

|       | Frequency vibration method | Lift-off method | Designed by RM software |
|-------|---------------------------|----------------|-------------------------|
| CVB 1 | 2361.42                  | 2565           | 2485                    |
| CVB 2 | 2571.83                  | 2733           | 2708                    |
| CVB 3 | 3453.96                  | 3366           | 3395                    |
| CVB 4 | 4178.63                  | 3931           | 3990                    |
| CVB 5 | 4544.99                  | 4433           | 4518                    |
| CVB 6 | 5213.40                  | 4992           | 4821                    |
| CVB 7 | 5330.41                  | 5135           | 5261                    |
| CVB 8 | 5921.60                  | 5667           | 5681                    |
| CVB 9 | 6351.18                  | 6191           | 6212                    |

**Table 5.** The cable force of each cable at pylon T30 in Bach Dang cable stayed Bridge in Viet Nam
when compare the internal cable force that determined by vibration testing and the lift-off method testing, the results as: The tension force value of lift-off method testing is higher than that calculated from the vibration testing 0-9% at both upstream and at downstream. Particularly, the cable No 10, 22 the difference value is 15.3%, 14.1% at upstream and the cable No 10, 11, 13, 21, 22 the difference value is -11%, 12%, 15%, 12%, and 14%.

Figure 12. Diagram of cable force at pylon T30 - upstream

The tension force at the cable of middle pylon, T29 from both testing method comparison with the designed value has a slight varying cable tension with less than 10%. The lift-off is more exactly than vibration in this.

Hole cables stayed in all 3 towers show that the cables in the middle of cable range toward the side of the tower position have tension values quite closely when measured by two methods and compared to the design value. The difference value between two measurement method and designed value appear in some positions are not large and the value varies from 0-5%. Whereas the cable stayed that near the top of the tower (cable No. 1 and cable number 13) and the 03 outside cable most have a big difference value when compare the measurement value by difference measurement methods. Specifically, at downstream of the bridge, there is a large difference between the measurements and the design, with the difference of the Pylon T28 is 17%, T29 is 11.7% with cable 1 and at the T30 the difference is 14.2% with cable 22.

4. Conclusion
A comparative field study of two tension measurement methods are carried out on a real three Pylons-cable-stayed bridge in this study. The lift-off test using a load cell, the vibration method using an accelerometer have been implemented for all cables of Bach Dang cable-stayed bridge under construction stage, before open for service. The results of this comparative study can be summarized as follows:
(1) The two methods are found to provide overall good estimates of varying cable tensions with less than 10% difference from the designed values.
(2) The measurement using the lift-off test is expensive instrumentation and human power, so it is used in the necessary case such as instant measurement and inspection at the construction site. The cable force measurement in this test method are little difference from that the design (less than 4%).
(3) The vibration test measure tensions show most tension cables are similar that by lift-off. However, the vibration test give more clearly the varying of edge cable tension with the length of cable is larger.

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