## I-621

# THE ULTIMATE STRENGTH OF A-SHAPED BRIDGE TOWERS UNDER CYCLIC LOADING

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## 1. Introduction

The purpose of this study is to create an analytical model of A-shaped bridge towers under cyclic loading in the plane perpendicular to the bridge axis, to compare results of the analytical model with previous test data, and to apply the analytical model with a new steel type. Tests of two A-shaped model towers are used. SHAPE-1 is a prototype of *Meiko-Nishi Cable-Stayed Bridge.* This tower has an A-shaped structure with straight legs until the base. For this type, four models of scale 1/30 with different member's sections are considered, two of them have bracing . SHAPE-2 is a prototype of *Konohana Self-Anchored Suspension Bridge.* This tower has A-shaped structure with inward leaning legs below the stiffening girder. Four models of scale 1/20 are considered. For comparison with A-shaped towers, one model of *portal frame tower* (SHAPE-3) is also considered. All types of the model towers are shown in Fig. 1.

## 2. Outline of the Test

Constant vertical loads equal to 27.5 % of the yield load were applied on the top of the model towers and a horizontal cyclic load was applied at the stiffening girder level. History of load-displacement and load-strain relationships, as well as maximum horizontal load, were experimentally investigated.

## 3. Outline of Numerical Analysis

Ultimate strength and load-displacement relationship of the model towers under the same loading conditions of the tests are computed numerically using the finite element program. Geometrical and material nonlinearities are also considered in the calculation. The comparison of the numerical calculations with the test data are shown in Table 1. The *yield displacement* $\delta_{yo}$ and the *yield load* $H_{yo}$ are defined as the displacement and load respectively at point A as shown in Fig. 1 when the first yielding occurs in the structure. Fig. 2 shows one example of the comparison between numerical results with the test data.

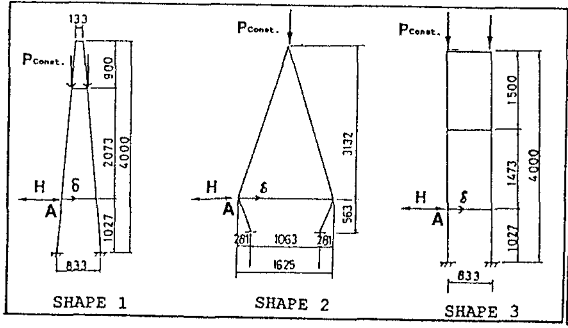


Fig.1 - Types of Model Towers

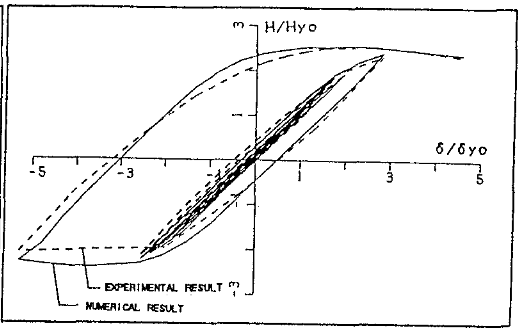


Fig.2 - The Comparison Between Experimental and Numerical Result of SHAPE-1 B Model Tower

Table 1 Comparison of Numerical Calculation with Experimental Data

| Tower Type | Column | Beam | Bracing | Calculation | | | Experimental | (1)/(2) |
|---|---|---|---|---|---|---|---|---|
| | | | | $\delta_{yo}$ (mm) | $H_{yo}$ (tonf) | $H_{max}$ cyclic (tonf) (1) | $H_{max}$ cyclic (tonf) (2) | |
| SHAPE-1 A | H100x100x6x8 | H100x100x6x8 | - | 4.81 | 2.55 | 5.08 | 5.20 | 0.977 |
| SHAPE-1 B | H150x75x5x7 | H150x75x5x7 | - | 4.55 | 0.91 | 2.33 | 2.39 | 0.977 |
| SHAPE-1 C | H100x100x6x8 | H100x100x6x8 | H100x50x6x8 | 0.90 | 9.64 | 32.84 | 32.10 | 1.023 |
| SHAPE-1 D | H100x100x6x8 | H100x100x6x8 | H100x50x6x8 | 0.90 | 9.82 | 33.44 | 33.12 | 1.010 |
| SHAPE-2 A | H125x125x6.5x9 | H125x125x6.5x9 | - | 1.54 | 3.83 | 13.52 | - | - |
| SHAPE-2 B | H125x125x6.5x9 | H125x60x6x8 | - | 1.74 | 2.74 | 12.37 | 14.20 | 0.871 |
| SHAPE-2 C | H125x125x6.5x9 | H125x125x6.5x9 | H100x50x5x7 | - | - | - | - | - |
| SHAPE-2 D | H150x150x7x10 | H150x150x7x10 | - | 1.09 | 4.29 | 21.55 | - | - |
| SHAPE-3 | H100x100x6x8 | H100x100x6x8 | - | 5.85 | 2.14 | 4.34 | 4.76 | 0.912 |

## 4. Study Using Different Type of Steels

The deformation capacity of the model tower with new steel type which has *high tensile strength with low yield ratio* is studied numerically [3]. For comparison purpose, the *high strength steel with high yield ratio* is also considered. The stress-strain curves from measured data for both types of steel are simplified for the purpose of numerical modeling as shown in Fig. 3. For comparison purpose, it is assumed that both steels have the same ultimate stress. *Kinematic hardening rule* is employed in this study. The deformation capacity ratio is defined as $\mu_{90} = \frac{\delta_{90}}{\delta_{yo}}$, where $\delta_{90}$ corresponds to displacement after loading has decreased to a value of 90 % of $H_{max}$. The comparison of results of both types of steels are shown in Table 2. Figure 4 and 5 show comparison of results of different shapes of towers and different types of steels.

Table 2 Numerical Results Using Different Types of Steels

| Tower Type | Low YR $\sigma_y$= 50 kgf/mm$^2$ | | | | High YR $\sigma_y$= 68 kgf/mm$^2$ | | | |
|---|---|---|---|---|---|---|---|---|
| | $\delta_{yo}$ (mm) | $H_{yo}$ (tonf) | $\mu_{90}$ | $\frac{H_{max}}{H_{yo}}$ | $\delta_{yo}$ (mm) | $H_{yo}$ (tonf) | $\mu_{90}$ | $\frac{H_{max}}{H_{yo}}$ |
| SHAPE-1 A | 7.42 | 3.40 | 5.8 | 2.12 | 10.30 | 4.53 | 4.9 | 1.95 |
| SHAPE-1 B | 9.00 | 1.39 | 4.2 | 2.08 | 12.65 | 1.67 | 3.2 | 1.77 |
| SHAPE-1 C | 1.43 | 14.33 | > 30 | ≈ 4.0 | 1.91 | 19.07 | 15.0 | 4.18 |
| SHAPE-1 D | 1.43 | 14.57 | > 30 | ≈ 4.0 | 1.91 | 19.39 | 15.0 | 4.18 |
| SHAPE-2 A | 2.14 | 4.77 | 14.4 | 3.53 | 2.97 | 6.22 | 10.6 | 3.20 |
| SHAPE-2 B | 2.53 | 3.38 | 7.8 | 3.53 | 3.54 | 4.15 | 6.1 | 3.10 |
| SHAPE-2 C | 1.12 | 15.21 | > 25 | ≈ 5.8 | 1.53 | 21.12 | > 25 | ≈ 5.7 |
| SHAPE-2 D | 1.65 | 5.75 | 18.4 | 4.38 | 2.27 | 7.66 | 14.1 | 4.03 |
| SHAPE-3 | 9.03 | 2.89 | 5.8 | 1.97 | 12.24 | 3.59 | 4.3 | 1.90 |

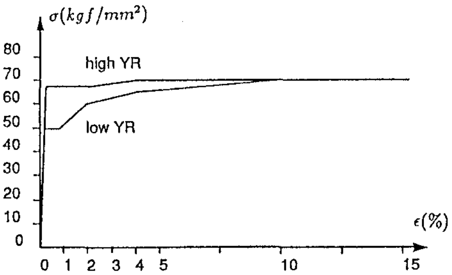
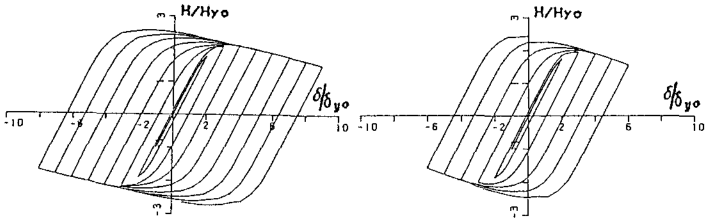


Fig.3-Stress-Strain Relationship for Steels



Low YR

High YR

Fig. 4 - Comparison Results of SHAPE-1A

## 5. Conclusions

Behaviors of the model towers subjected to a horizontal cyclic load are significantly affected by the geometrical shape of their lower parts. The lower parts of SHAPE-1 and SHAPE-3 being geometrically similar have similar behaviors. Figure 5 shows that SHAPE-2 model tower has higher $H_{max}/H_{yo}$ ratio than the others shapes and towers with low yield ratio steel have more reserved strength and deformation capacity in inelastic range compared to towers with high yield ratio steel.

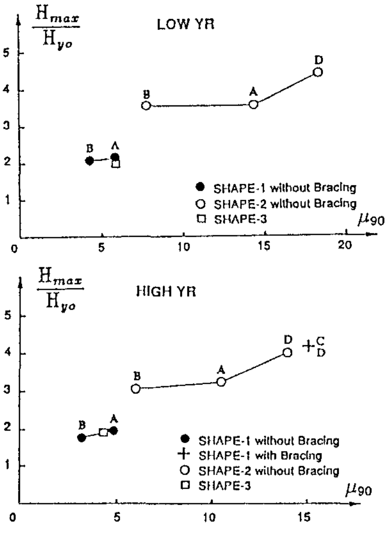


Fig. 5 - Deformation Capacities of Towers

## 6. References

[1] Fukumoto, Y., Itoh, Y. and Katsuya, M., Theoretical and Experimental studies on In-plane Strength of Towers of the Meikonishi-Ohashi Cable-Stayed Bridge, NUCE Research Report No: 8101, 1981 (in Japanese).

[2] Fukumoto, Y., Usami, T. and Itoh, Y., Experimental Studies on the Strength of Framed Tower of Hokko-Renraku Bridge, NUCE Research Report No: 8201, 1982 (in Japanese).

[3] Y. Simura and H. Kuwamura, Experiment on High-Strength Steel Beam with Different Yield Ratios, Transaction of The Architectural Institute of Japan, 1987, pp. 873 - 874 (in Japanese).