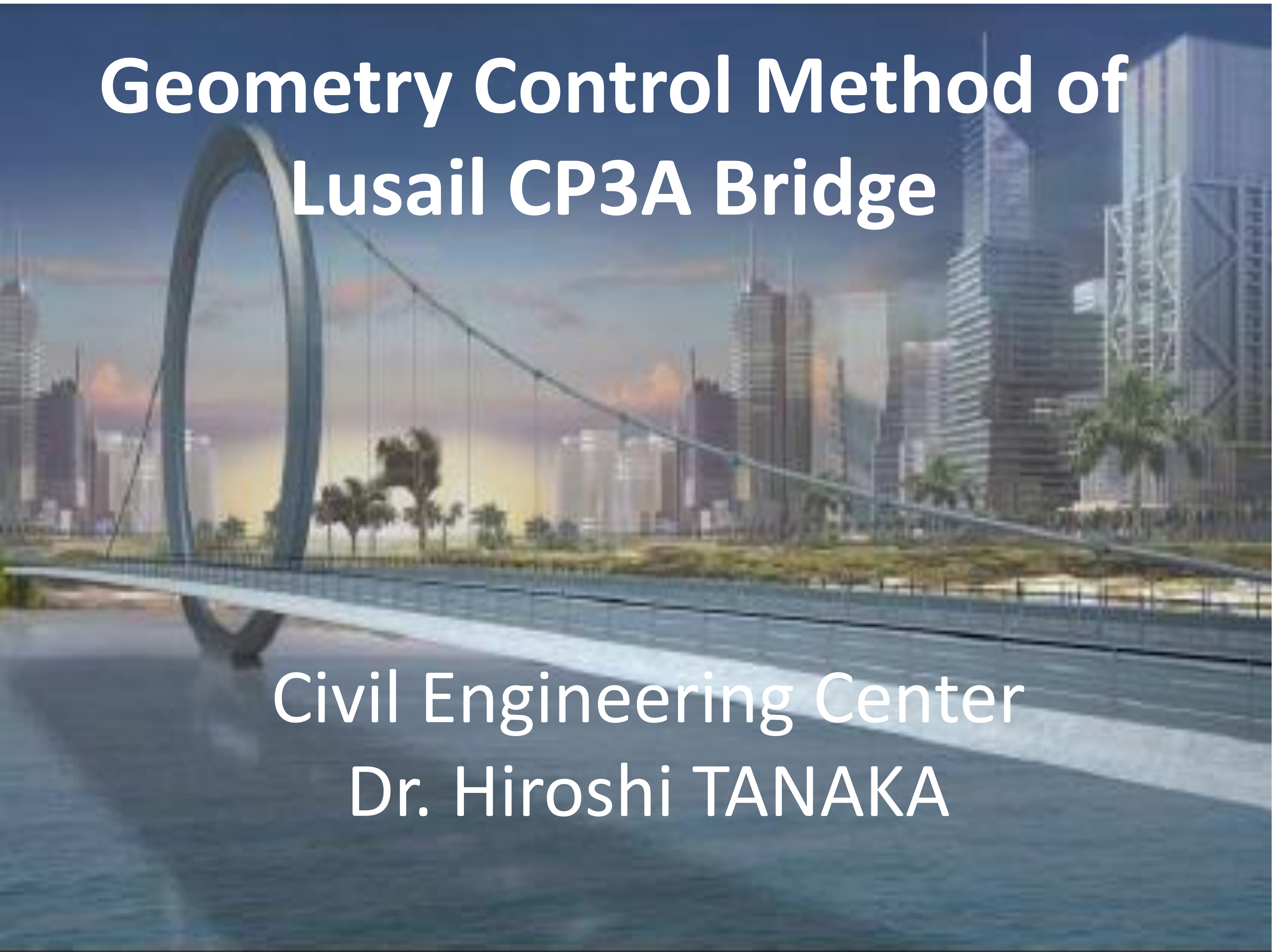
Geometry Control Method of Lusail CP3A Bridge



Civil Engineering Center
Dr. Hiroshi TANAKA

Contents

Geometry Control ?

- Shape bridge up within geometry allowance of Lusail CP3A

- Hanger Tension Force : Error < 10%

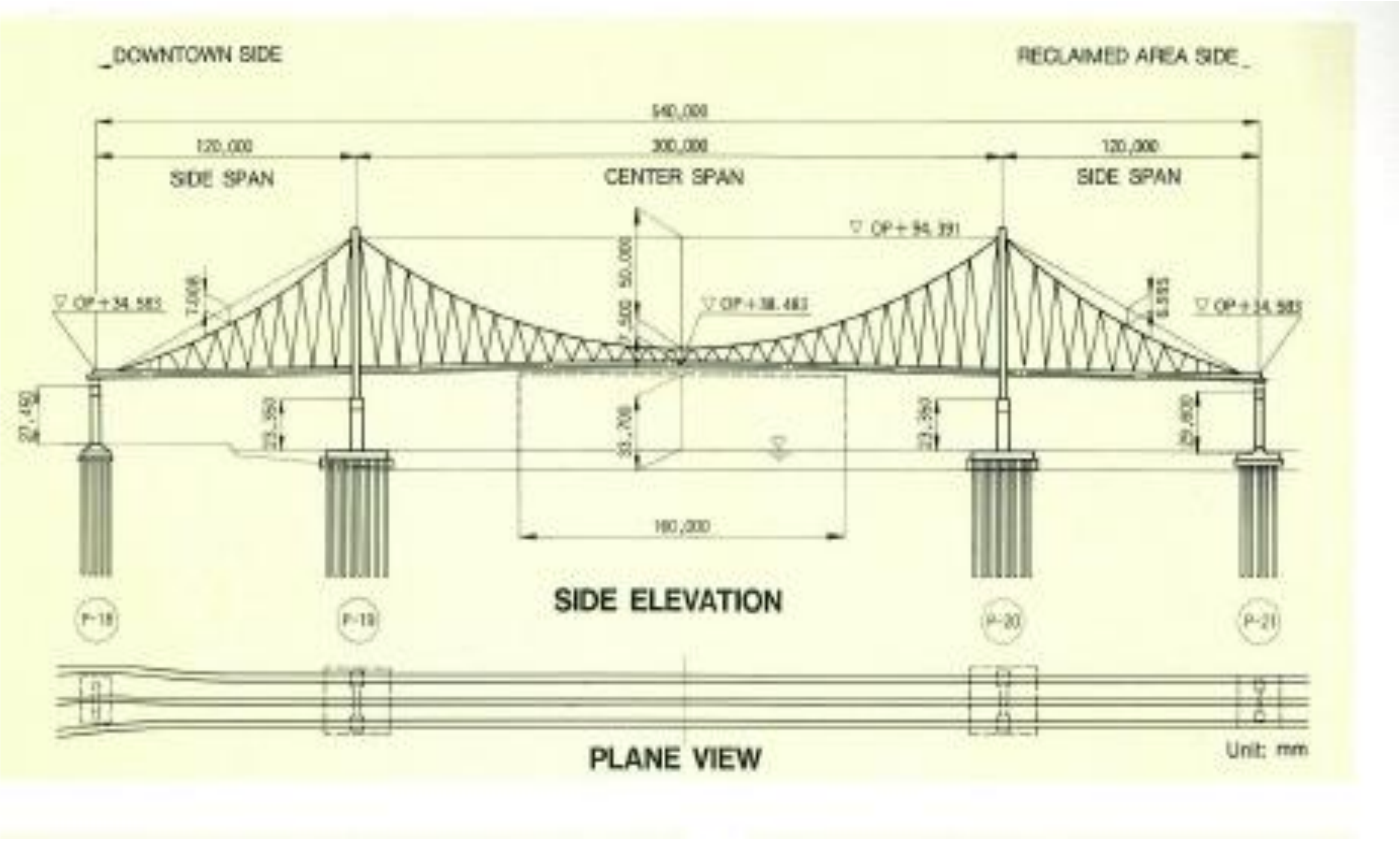
- Very Hard to realize !!

Konohana Bridge

Self Anchored Suspension Bridge with Inclined hangers

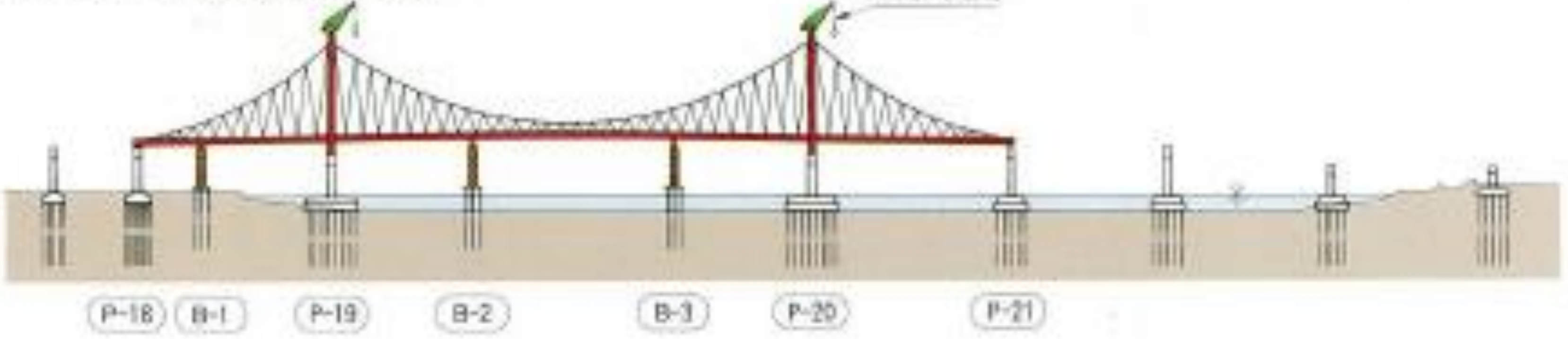
Located in Osaka Japan, 1986

General View of Konohana Bridge

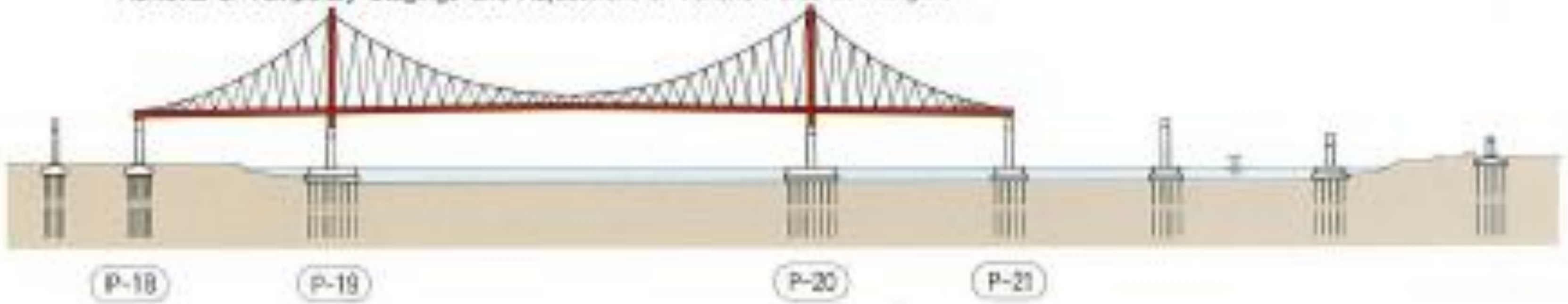


Bents Removal

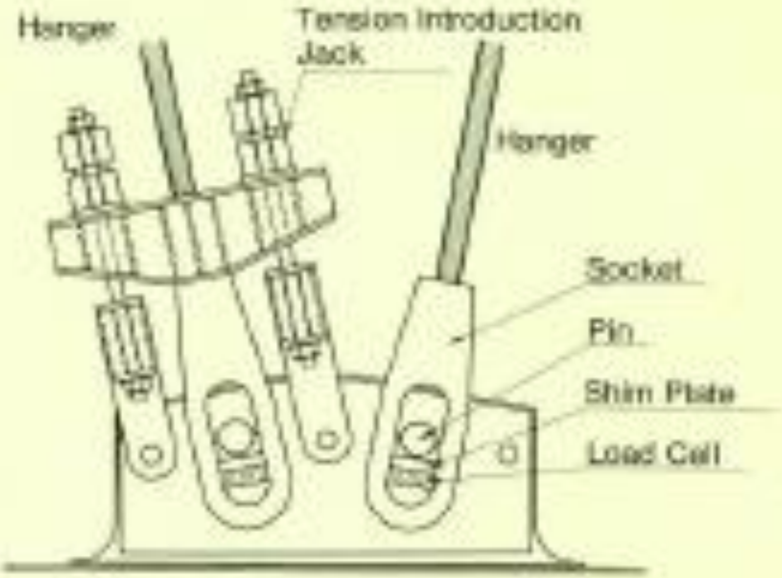
STEP 7 Erection of Cables and Hangers



STEP 8 Jacking down of Main Girder at Temporary Stagings
Removal of Temporary Stagings and Adjustment of Tensile Force in Hangers



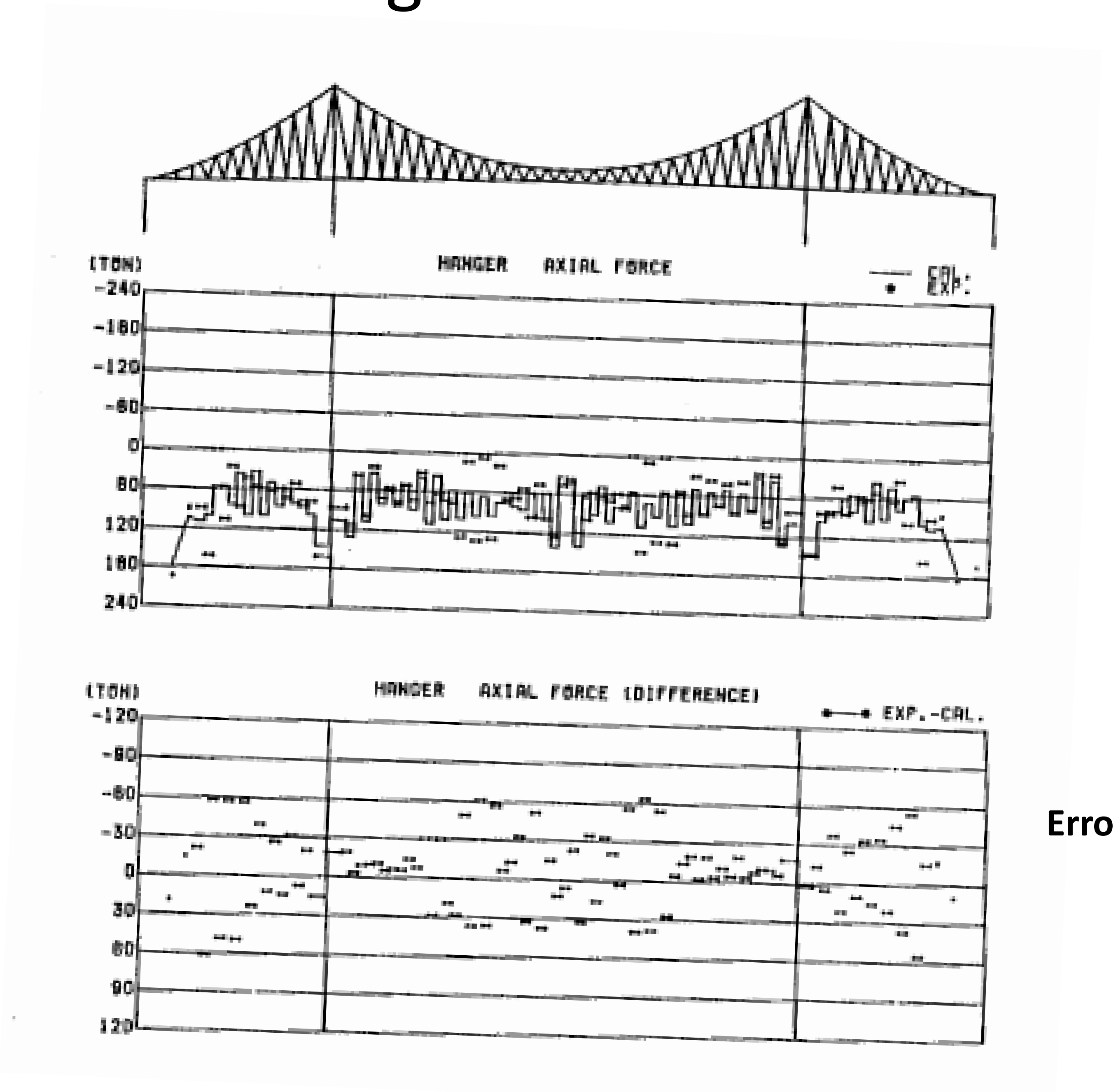
Hanger Anchor Part



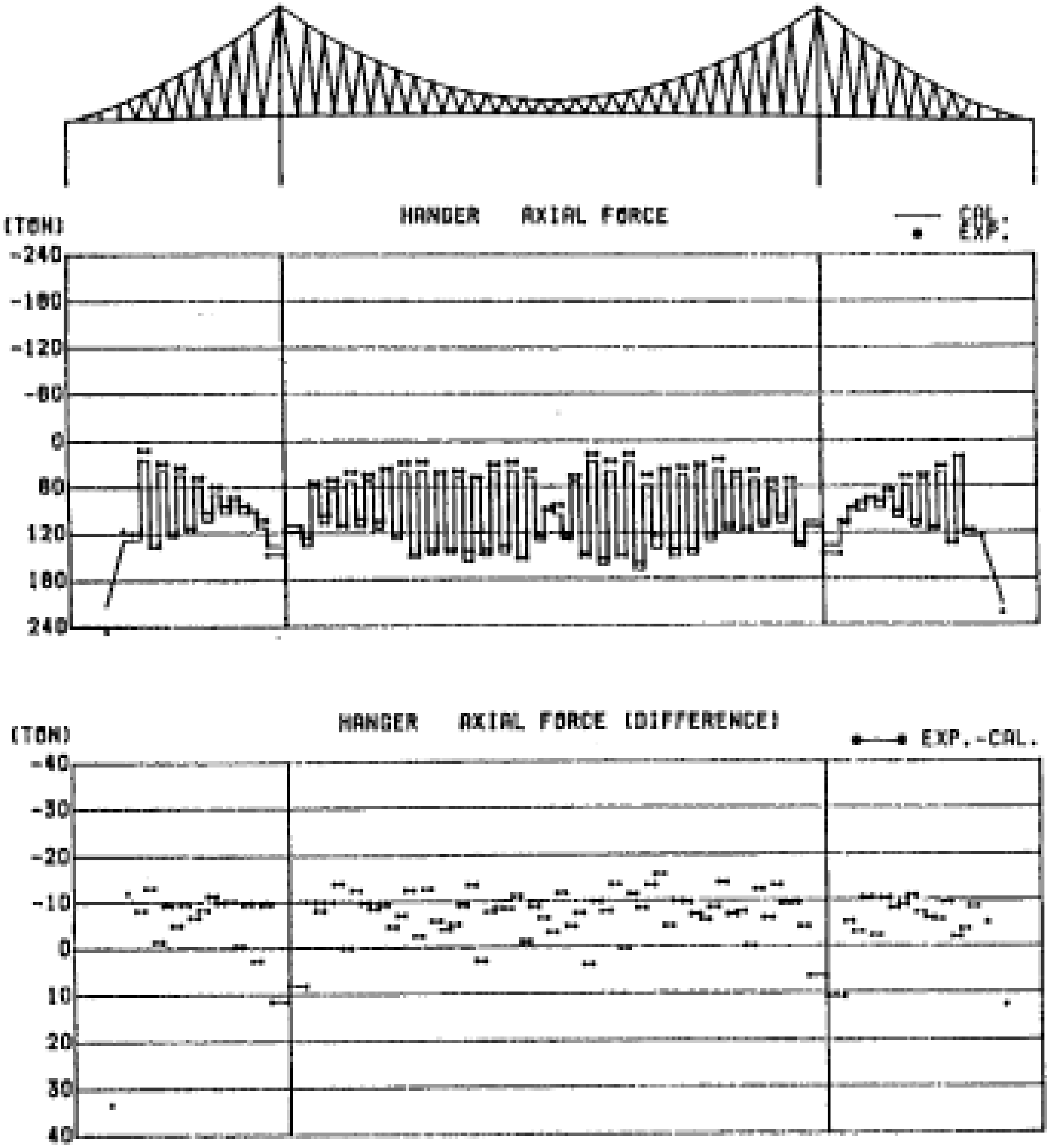
CONNECTION OF HANGERS
(INTRODUCTION OF TENSILE FORCE)

Cable Tension Adjustment Work at Site

Hanger Tension Error



Errors are large !

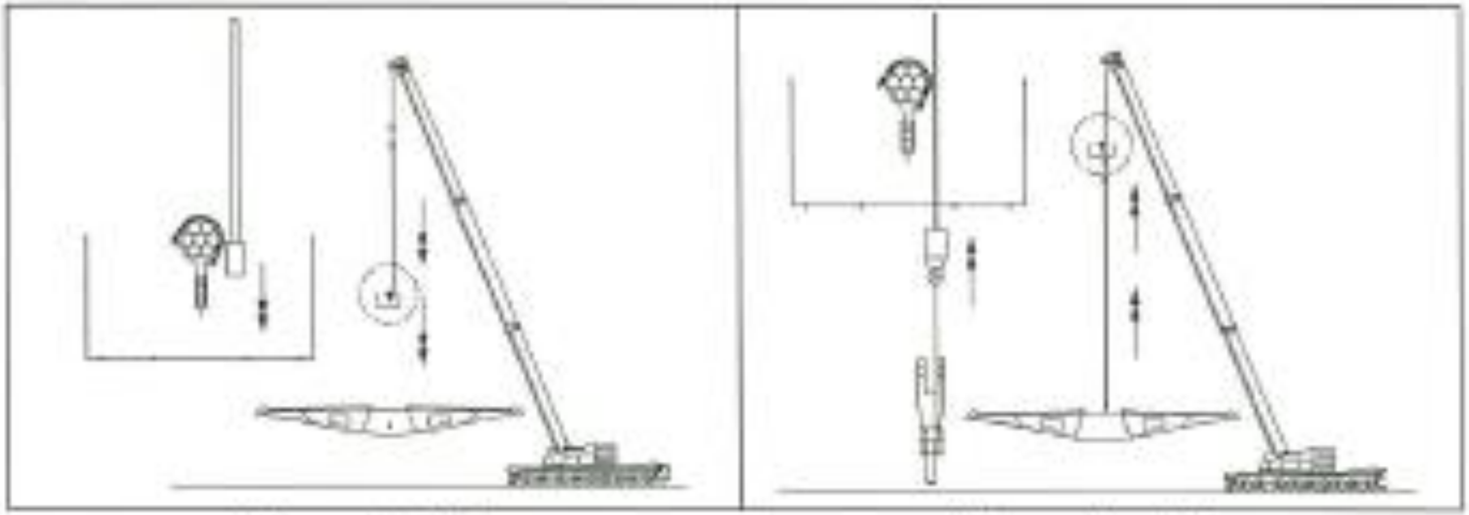


Errors are within allowance !
± 20 ton

Main Cable Installation

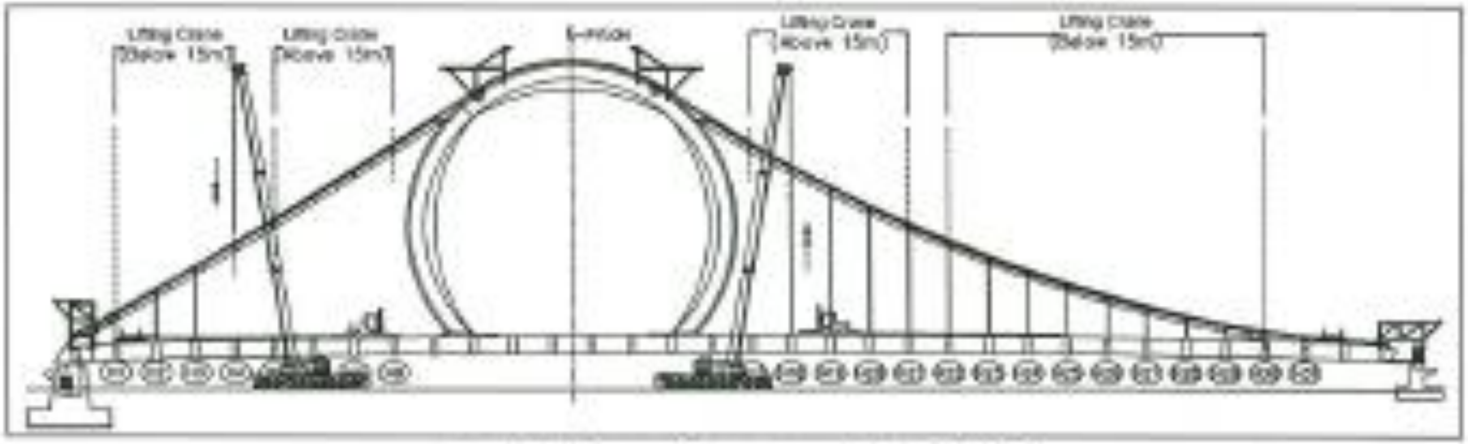
Temporary Bents

Hanger Installation



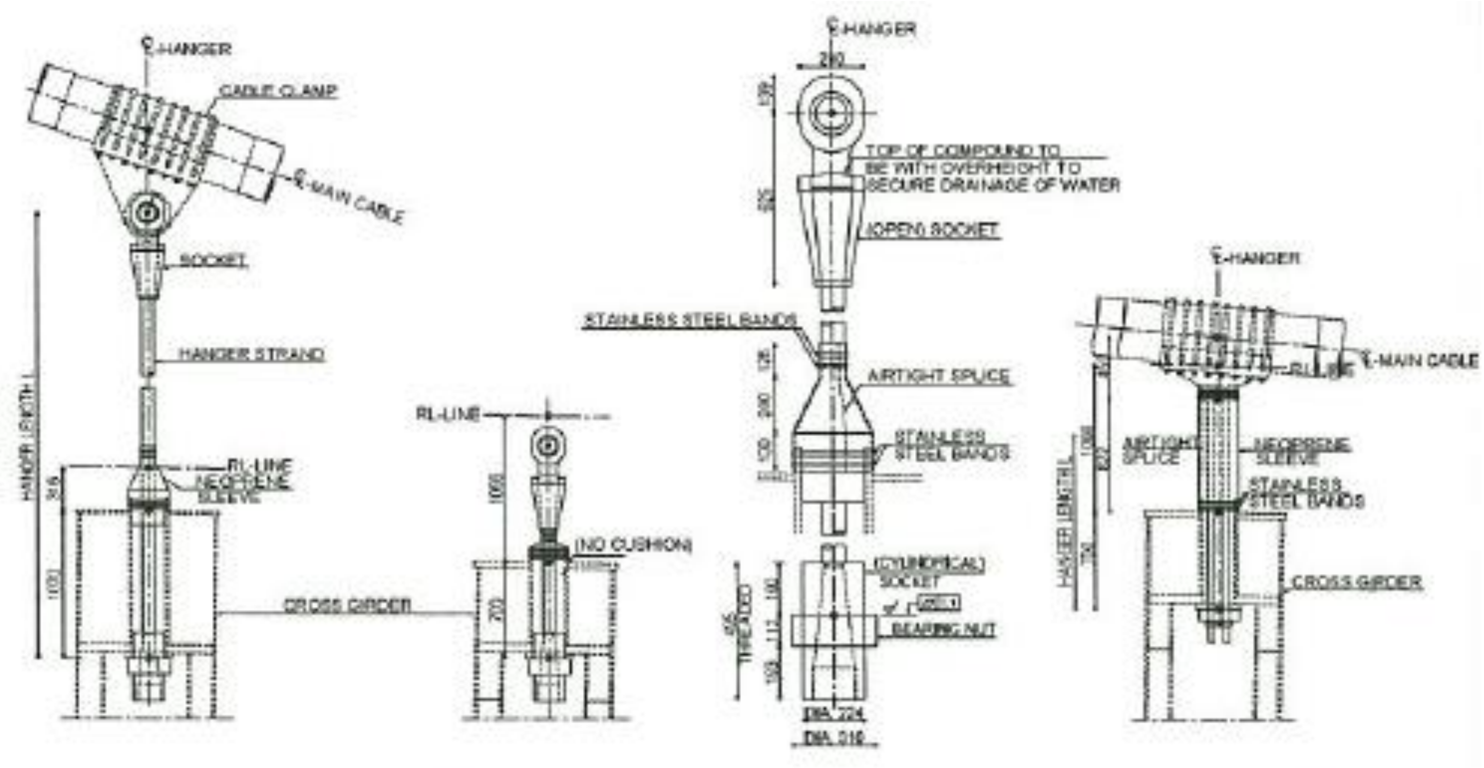
Below about 15m

Above about 15m



Installation of hanger cable in Br 8

Hanger System



[H1 type]

[H2 type]

Hanger Tension Adjustment System

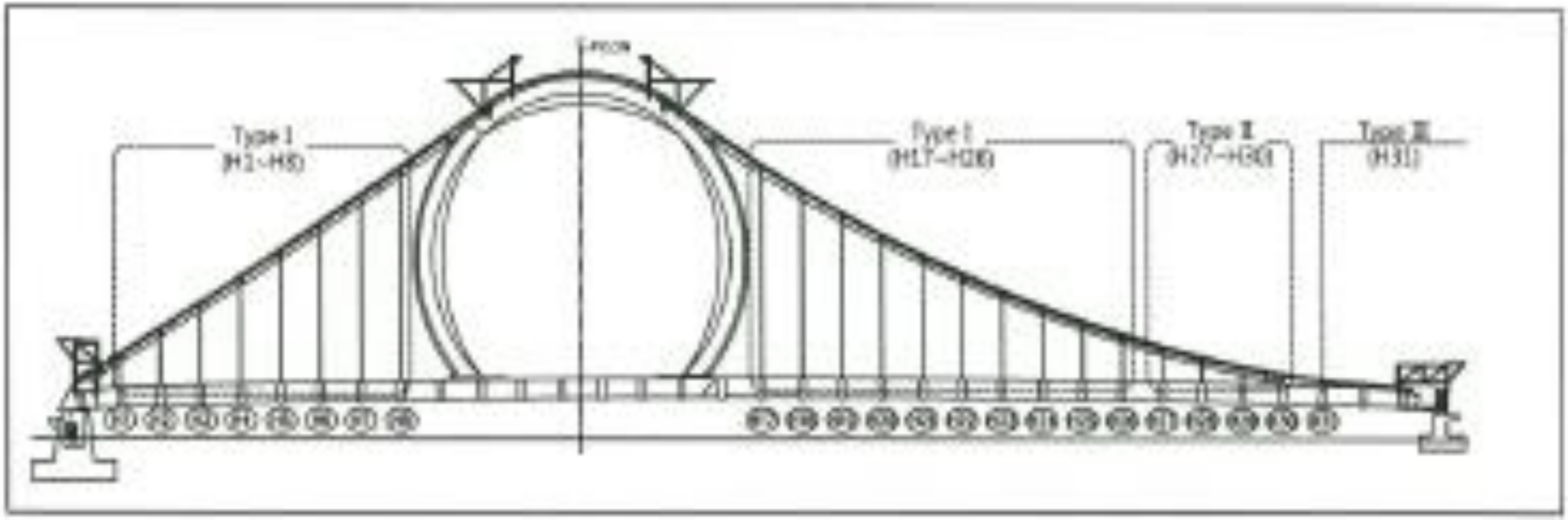

Bolt Tensioner Fit up Test


Bolt Tensioner Fit up Test


New Tensioner Mock Up


New Tensioner Mock Up

Bents Removal

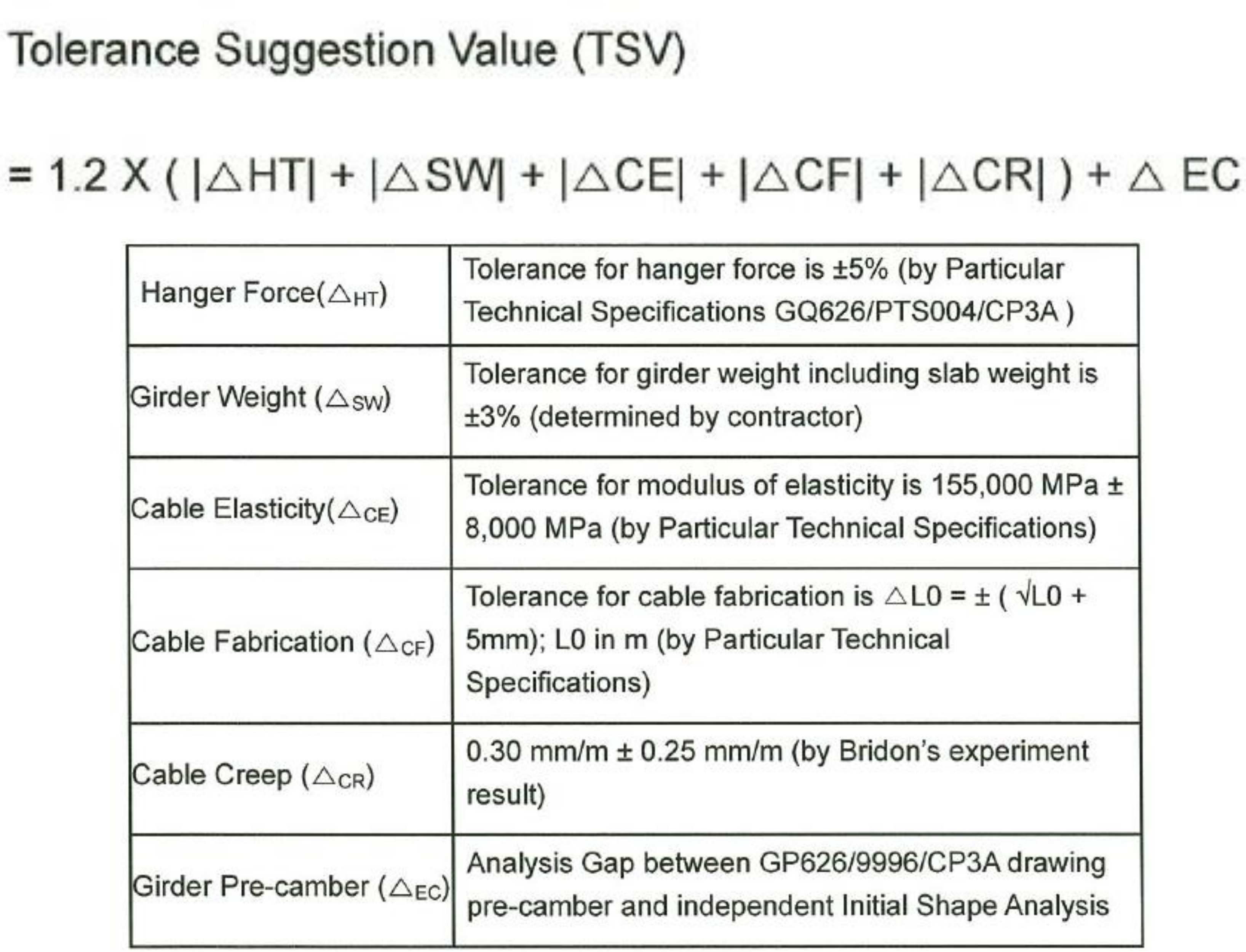


Br 8

Geometry Survey

Survey Location

Error Factors



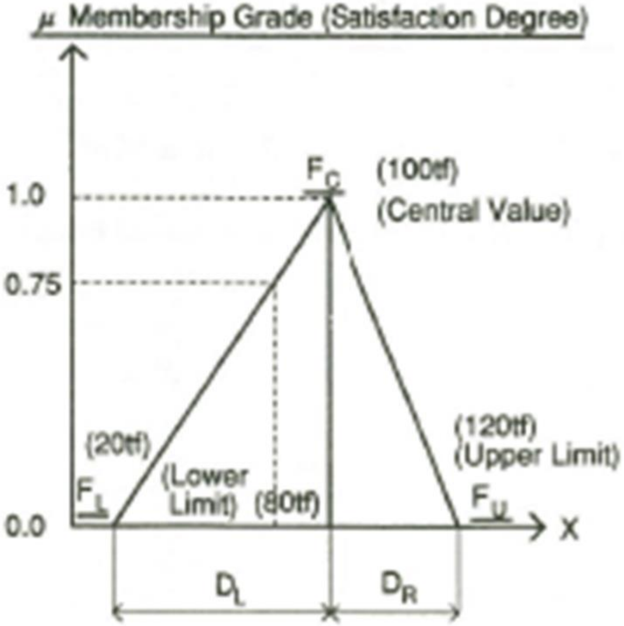
Tolerance Suggestion Value (TSV)

$$= 1.2 \times (|\triangle HT| + |\triangle SW| + |\triangle CE| + |\triangle CF| + |\triangle CR|) + \triangle EC$$

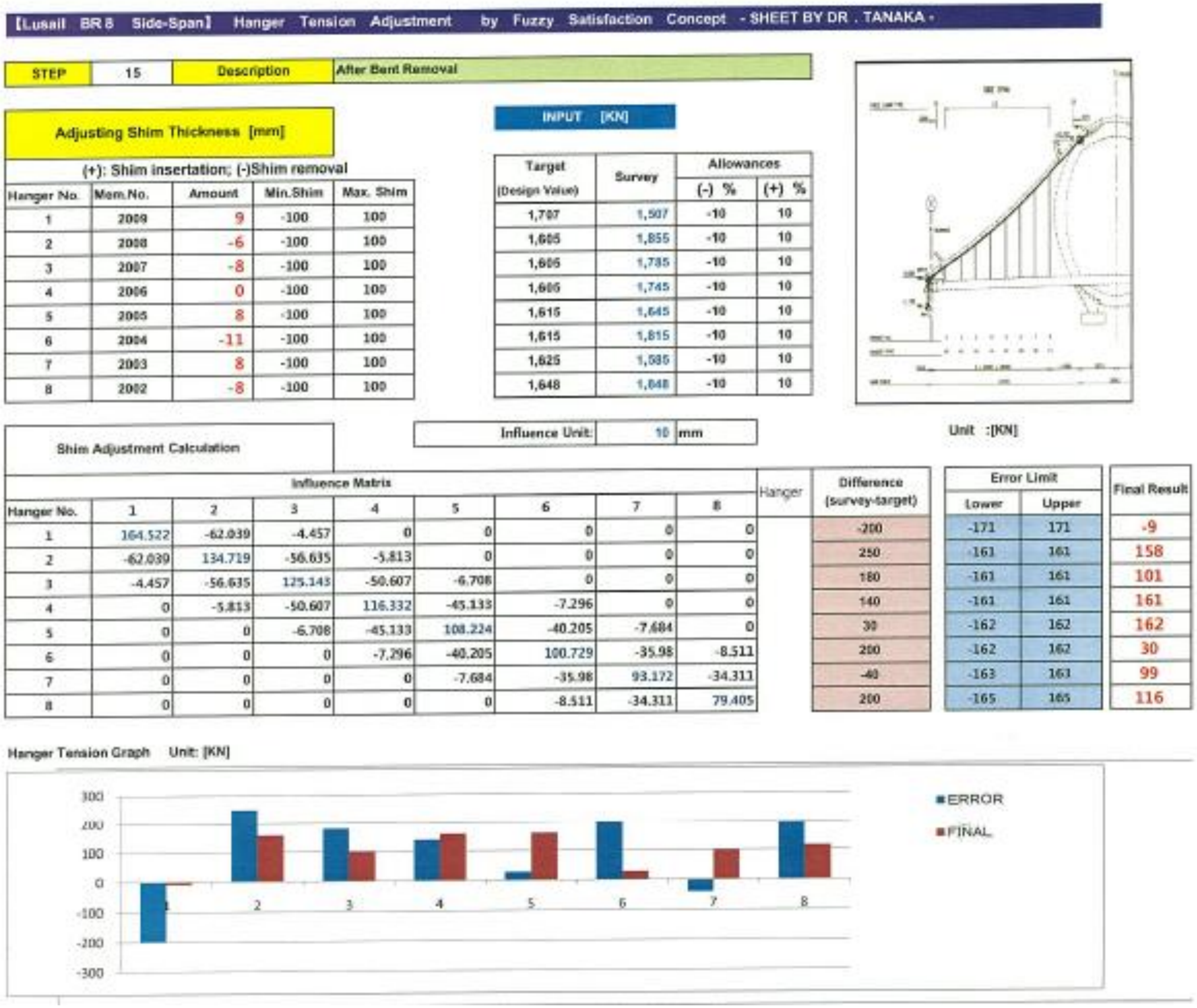
Hanger Force($\triangle_{HT}$)	Tolerance for hanger force is ±5% (by Particular Technical Specifications GQ626/PTS004/CP3A)
Girder Weight ($\triangle_{SW}$)	Tolerance for girder weight including slab weight is ±3% (determined by contractor)
Cable Elasticity($\triangle_{CE}$)	Tolerance for modulus of elasticity is 155,000 MPa ± 8,000 MPa (by Particular Technical Specifications)
Cable Fabrication ($\triangle_{CF}$)	Tolerance for cable fabrication is $\triangle L0 = \pm (\sqrt{L0} + 5mm)$; L0 in m (by Particular Technical Specifications)
Cable Creep ($\triangle_{CR}$)	0.30 mm/m ± 0.25 mm/m (by Bridon's experiment result)
Girder Pre-camber ($\triangle_{EC}$)	Analysis Gap between GP626/9996/CP3A drawing pre-camber and independent Initial Shape Analysis

Applied Theory

- Fuzzy satisfaction concept
- Designer’s satisfaction → Maximum



Side Span of Lusail 3CPA Bridge 8



【Lusail BR 8 Side-Span】 Hanger Tension Adjustment by Fuzzy Satisfaction Concept - SHEET BY DR . TANAKA -

STEP	15	Description	After Bent Removal

Adjusting Shim Thickness [mm]

(+): Shim insertation; (-)Shim removal

Hanger No.	Mem.No.	Amount	Min.Shim	Max. Shim
1	2009	9	-100	100
2	2008	-6	-100	100
3	2007	-8	-100	100
4	2006	0	-100	100
5	2005	8	-100	100
6	2004	-11	-100	100
7	2003	8	-100	100
8	2002	-8	-100	100

INPUT [KN]

Target (Design Value)	Survey	Allowances	
		(-) %	(+) %
1,707	1,507	-10	10
1,605	1,855	-10	10
1,605	1,785	-10	10
1,605	1,745	-10	10
1,615	1,645	-10	10
1,615	1,815	-10	10
1,625	1,585	-10	10
1,648	1,848	-10	10

Influence Unit:	10	mm

Unit :[KN]

Shim Adjustment Calculation

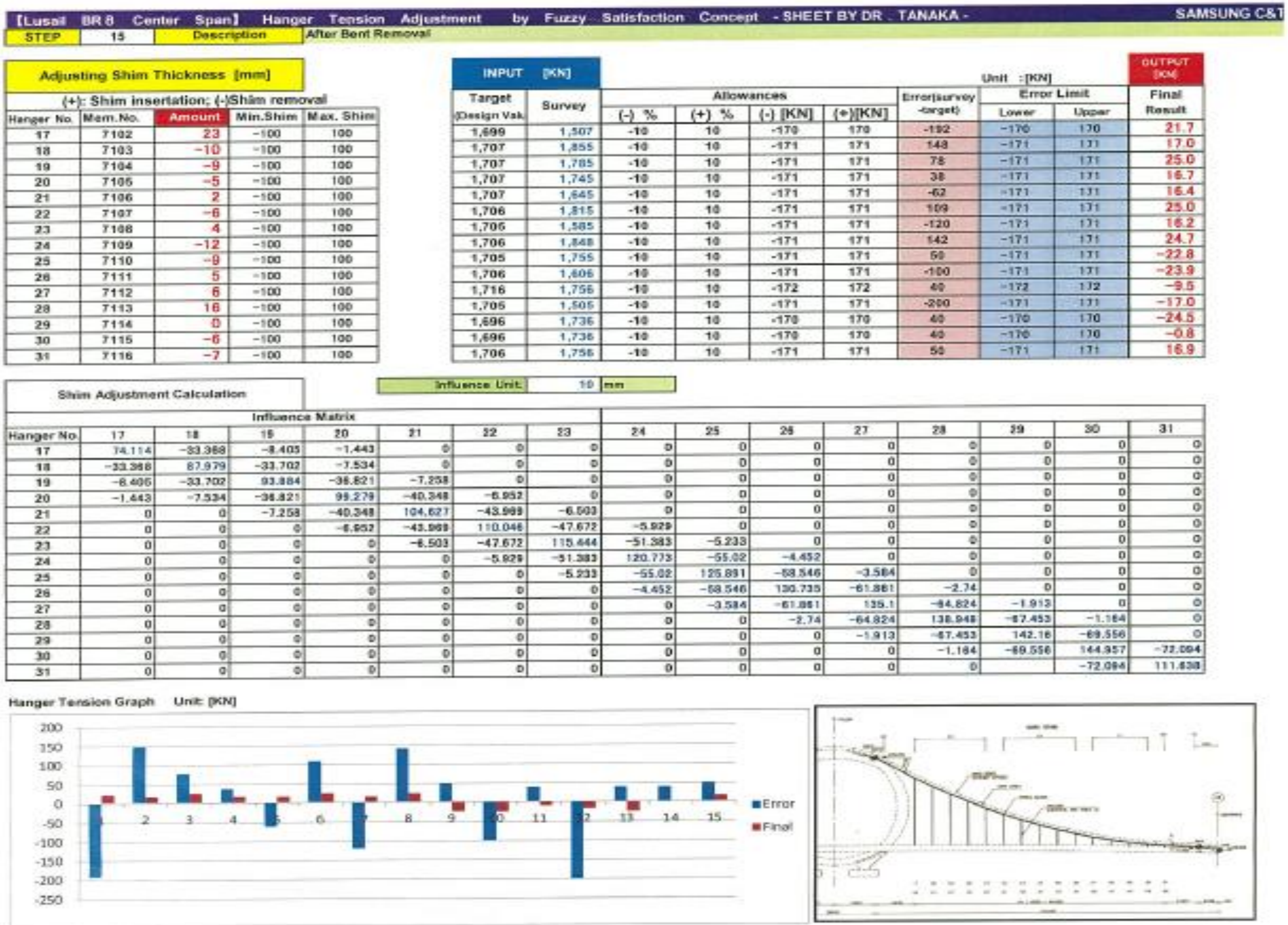
Influence Matrix

Hanger No.	1	2	3	4	5	6	7	8
1	164.522	-62.039	-4.457	0	0	0	0	0
2	-62.039	134.719	-56.635	-5.813	0	0	0	0
3	-4.457	-56.635	125.143	-50.607	-6.708	0	0	0
4	0	-5.813	-50.607	116.332	-45.133	-7.296	0	0
5	0	0	-6.708	-45.133	108.224	-40.205	-7.684	0
6	0	0	0	-7.296	-40.205	100.729	-35.98	-8.511
7	0	0	0	0	-7.684	-35.98	93.172	-34.311
8	0	0	0	0	0	-8.511	-34.311	79.405

Hanger	Difference (survey-target)	Error Limit		Final Result
		Lower	Upper	
	-200	-171	171	-9
	250	-161	161	158
	180	-161	161	101
	140	-161	161	161
	30	-162	162	162
	200	-162	162	30
	-40	-163	163	99
	200	-165	165	116

Hanger Tension Graph Unit: [KN]

Center Span of Lusail 3CPA Bridge 8



【Lusail BR 8 Center Span】 Hanger Tension Adjustment by Fuzzy Satisfaction Concept - SHEET BY DR . TANAKA - SAMSUNG C&T

STEP	15	Description	After Bent Removal

Adjusting Shim Thickness [mm]

(+): Shim insertation; (-)Shim removal

Hanger No.	Mem.No.	Amount	Min.Shim	Max. Shim
17	7102	23	-100	100
18	7103	-10	-100	100
19	7104	-9	-100	100
20	7105	-5	-100	100
21	7106	2	-100	100
22	7107	-6	-100	100
23	7108	4	-100	100
24	7109	-12	-100	100
25	7110	-9	-100	100
26	7111	5	-100	100
27	7112	6	-100	100
28	7113	16	-100	100
29	7114	0	-100	100
30	7115	-6	-100	100
31	7116	-7	-100	100

INPUT [KN] Unit :[KN] **OUTPUT [KN]**

Target (Design Val.	Survey	Allowances				Error(survey -target)	Error Limit		Final Result
		(-) %	(+) %	(-) [KN]	(+)[KN]		Lower	Upper	
1,699	1,507	-10	10	-170	170	-192	-170	170	21.7
1,707	1,855	-10	10	-171	171	148	-171	171	17.0
1,707	1,785	-10	10	-171	171	78	-171	171	25.0
1,707	1,745	-10	10	-171	171	38	-171	171	16.7
1,707	1,645	-10	10	-171	171	-62	-171	171	16.4
1,706	1,815	-10	10	-171	171	109	-171	171	25.0
1,705	1,585	-10	10	-171	171	-120	-171	171	16.2
1,706	1,848	-10	10	-171	171	142	-171	171	24.7
1,705	1,755	-10	10	-171	171	50	-171	171	-22.8
1,706	1,606	-10	10	-171	171	-100	-171	171	-23.9
1,716	1,756	-10	10	-172	172	40	-172	172	-9.5
1,705	1,505	-10	10	-171	171	-200	-171	171	-17.0
1,696	1,736	-10	10	-170	170	40	-170	170	-24.5
1,696	1,736	-10	10	-170	170	40	-170	170	-0.8
1,706	1,756	-10	10	-171	171	50	-171	171	16.9

Influence Unit	10	mm

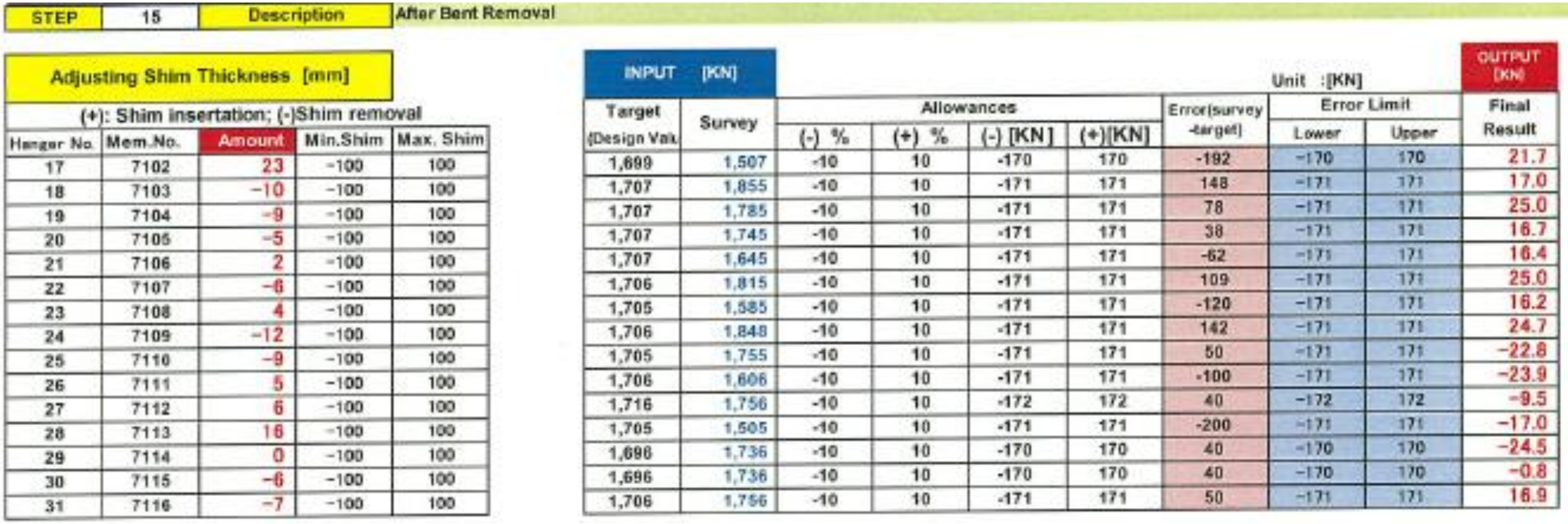
Shim Adjustment Calculation

Influence Matrix

Hanger No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
17	74.114	-33.368	-8.405	-1.443	0	0	0	0	0	0	0	0	0	0	0
18	-33.368	87.979	-33.702	-7.534	0	0	0	0	0	0	0	0	0	0	0
19	-8.405	-33.702	93.884	-36.821	-7.258	0	0	0	0	0	0	0	0	0	0
20	-1.443	-7.534	-36.821	99.279	-40.348	-6.952	0	0	0	0	0	0	0	0	0
21	0	0	-7.258	-40.348	104.627	-43.969	-6.503	0	0	0	0	0	0	0	0
22	0	0	0	-6.952	-43.969	110.046	-47.672	-5.929	0	0	0	0	0	0	0
23	0	0	0	0	-6.503	-47.672	115.444	-51.383	-5.233	0	0	0	0	0	0
24	0	0	0	0	0	-5.929	-51.383	120.773	-55.02	-4.452	0	0	0	0	0
25	0	0	0	0	0	0	-5.233	-55.02	125.891	-58.546	-3.584	0	0	0	0
26	0	0	0	0	0	0	0	-4.452	-58.546	130.735	-61.861	-2.74	0	0	0
27	0	0	0	0	0	0	0	0	-3.584	-61.861	135.1	-64.824	-1.913	0	0
28	0	0	0	0	0	0	0	0	0	-2.74	-64.824	138.948	-67.453	-1.164	0
29	0	0	0	0	0	0	0	0	0	0	-1.913	-67.453	142.16	-69.556	0
30	0	0	0	0	0	0	0	0	0	0	0	-1.164	-69.556	144.957	-72.094
31	0	0	0	0	0	0	0	0	0	0	0	0		-72.094	111.838

Hanger Tension Graph Unit: [KN]

INPUT & OUTPUT (1)



STEP	15	Description	After Bent Removal

Adjusting Shim Thickness [mm]

(+): Shim insertation; (-)Shim removal

Hanger No.	Mem.No.	Amount	Min.Shim	Max. Shim
17	7102	23	-100	100
18	7103	-10	-100	100
19	7104	-9	-100	100
20	7105	-5	-100	100
21	7106	2	-100	100
22	7107	-6	-100	100
23	7108	4	-100	100
24	7109	-12	-100	100
25	7110	-9	-100	100
26	7111	5	-100	100
27	7112	6	-100	100
28	7113	16	-100	100
29	7114	0	-100	100
30	7115	-6	-100	100
31	7116	-7	-100	100

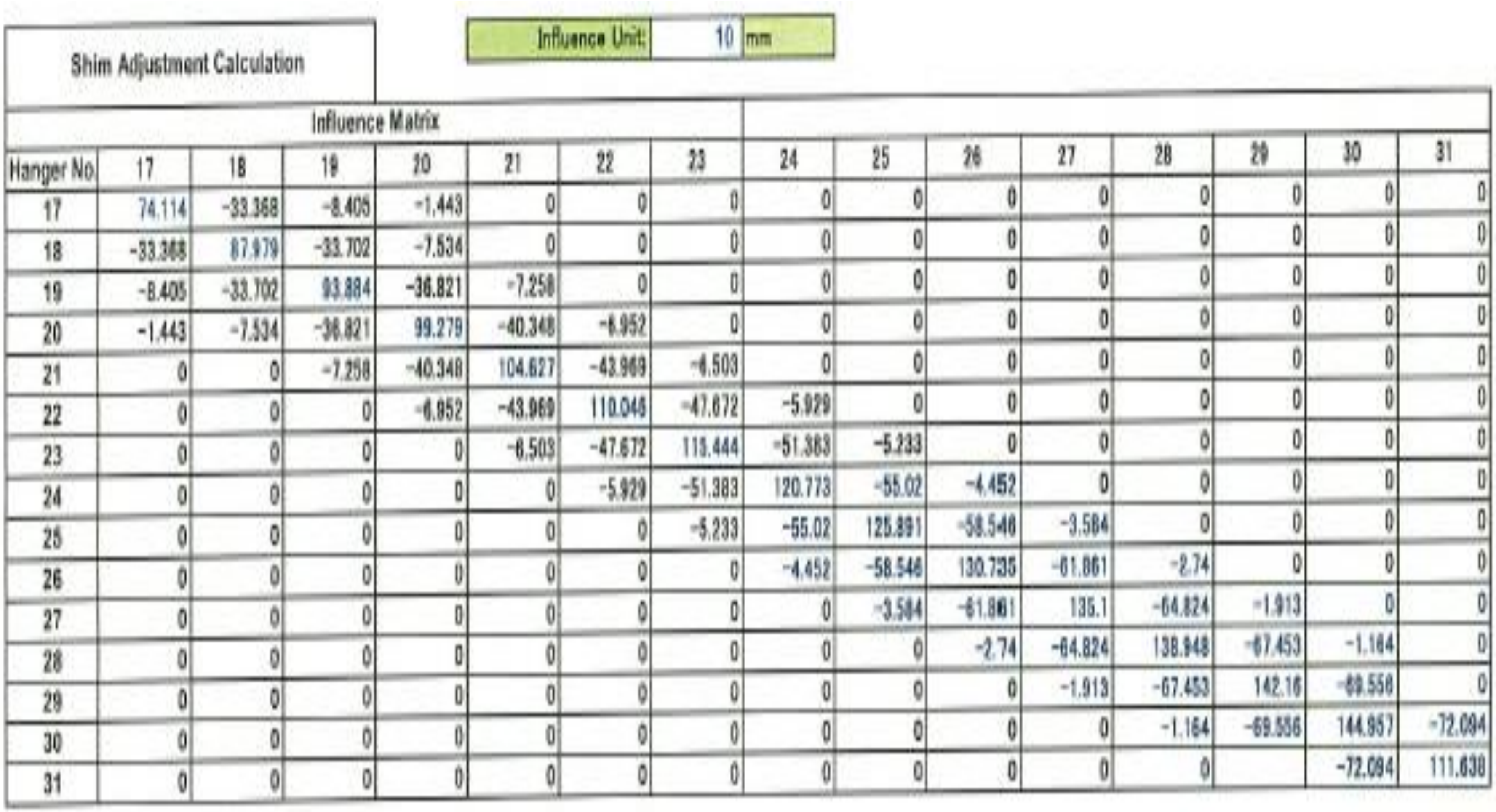
INPUT [KN]

Unit :[KN]

OUTPUT [KN]

Target (Design Valu	Survey	Allowances				Error(survey -target)	Error Limit		Final Result
		(-) %	(+) %	(-) [KN]	(+)[KN]		Lower	Upper	
1,699	1,507	-10	10	-170	170	-192	-170	170	21.7
1,707	1,855	-10	10	-171	171	148	-171	171	17.0
1,707	1,785	-10	10	-171	171	78	-171	171	25.0
1,707	1,745	-10	10	-171	171	38	-171	171	16.7
1,707	1,645	-10	10	-171	171	-62	-171	171	16.4
1,706	1,815	-10	10	-171	171	109	-171	171	25.0
1,705	1,585	-10	10	-171	171	-120	-171	171	16.2
1,706	1,848	-10	10	-171	171	142	-171	171	24.7
1,705	1,755	-10	10	-171	171	50	-171	171	-22.8
1,706	1,606	-10	10	-171	171	-100	-171	171	-23.9
1,716	1,756	-10	10	-172	172	40	-172	172	-9.5
1,705	1,505	-10	10	-171	171	-200	-171	171	-17.0
1,696	1,736	-10	10	-170	170	40	-170	170	-24.5
1,696	1,736	-10	10	-170	170	40	-170	170	-0.8
1,706	1,756	-10	10	-171	171	50	-171	171	16.9

INPUT & OUTPUT (2)



Shim Adjustment Calculation

Influence Unit: 10 mm

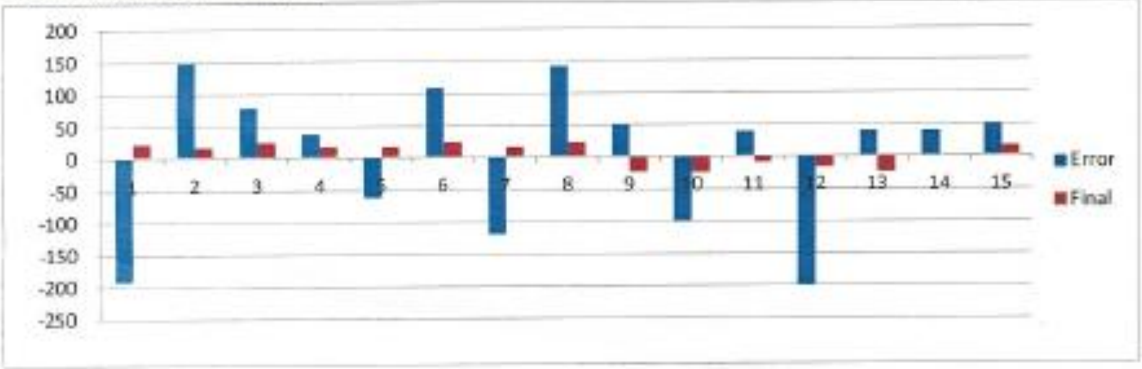
Influence Matrix

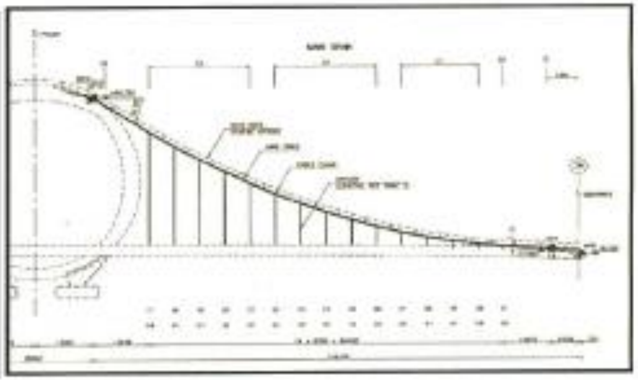
Hanger No	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
17	74.114	-33.368	-8.405	-1.443	0	0	0	0	0	0	0	0	0	0	0
18	-33.368	87.979	-33.702	-7.534	0	0	0	0	0	0	0	0	0	0	0
19	-8.405	-33.702	93.884	-36.821	-7.258	0	0	0	0	0	0	0	0	0	0
20	-1.443	-7.534	-36.821	99.279	-40.348	-6.952	0	0	0	0	0	0	0	0	0
21	0	0	-7.258	-40.348	104.627	-43.969	-6.503	0	0	0	0	0	0	0	0
22	0	0	0	-6.952	-43.969	110.046	-47.672	-5.929	0	0	0	0	0	0	0
23	0	0	0	0	-6.503	-47.672	115.444	-51.383	-5.233	0	0	0	0	0	0
24	0	0	0	0	0	-5.929	-51.383	120.773	-55.02	-4.452	0	0	0	0	0
25	0	0	0	0	0	0	-5.233	-55.02	125.891	-58.546	-3.584	0	0	0	0
26	0	0	0	0	0	0	0	-4.452	-58.546	130.735	-61.861	-2.74	0	0	0
27	0	0	0	0	0	0	0	0	-3.584	-61.861	135.1	-64.824	-1.913	0	0
28	0	0	0	0	0	0	0	0	0	-2.74	-64.824	138.948	-67.453	-1.164	0
29	0	0	0	0	0	0	0	0	0	0	-1.913	-67.453	142.16	-69.558	0
30	0	0	0	0	0	0	0	0	0	0	0	-1.164	-69.556	144.957	-72.094
31	0	0	0	0	0	0	0	0	0	0	0	0		-72.094	111.638

N.B.) Precise Influence Matrix is necessary

INPUT & OUTPUT (3)

Hanger Tension Graph Unit: [KN]





Difference between self-anchored suspension bridges and cable stay bridges

- Hangers of self-anchored suspension bridges can not control erection errors of decks and towers .

  Therefore erection of decks and towers should be done carefully.

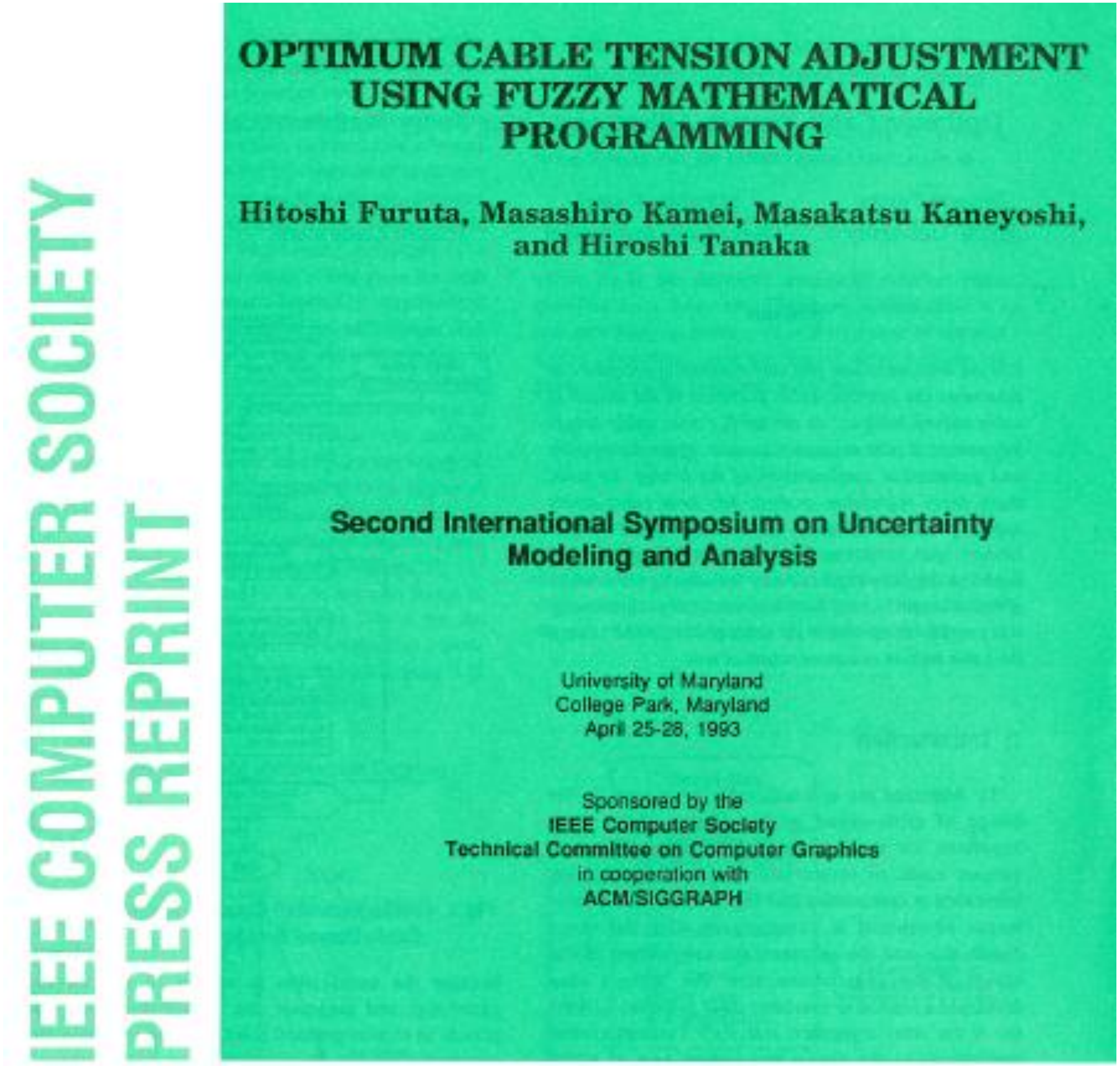
Conclusions

- Cable tension adjustment is vital for cable suspended bridges.
- Lusail CP3A bridges also needs this system.
- We can realize precise construction by this system.
- Applying this software we can save time and money.

We sincerely hope perfect construction of Lusail CP3A.

Then Samsung can receive client’s highest evaluation.

Appendix Used Basic Theory



IEEE COMPUTER SOCIETY
PRESS REPRINT

OPTIMUM CABLE TENSION ADJUSTMENT USING FUZZY MATHEMATICAL PROGRAMMING

Hitoshi Furuta, Masashiro Kamei, Masakatsu Kaneyoshi,
and Hiroshi Tanaka

Second International Symposium on Uncertainty
Modeling and Analysis

University of Maryland
College Park, Maryland
April 25-28, 1993

Sponsored by the
IEEE Computer Society
Technical Committee on Computer Graphics
in cooperation with
ACM/SIGGRAPH

1: Introduction

To determine the optimum cable prestresses in the design of cable-stayed bridges is one of the most important, but time consuming procedure. However, various kinds of errors will be introduced during fabrication or construction (see Fig. 1)[1]. Therefore, cable length adjustment is necessary to alter the stress distribution and the geometrical configuration of the bridge at the construction site. The authors have developed a method to overcome these problems with the aid of the fuzzy regression analysis[2]. Through several applications in the design and construction of actual cable-stayed bridges, it has been proved that the method is not only simple to handle, but also very practical for the design and construction of cable-stayed bridges.

In this paper, an attempt is made to improve the method by introducing the concept of "satisfaction". The degree of satisfaction is defined in such a way that when the aspire of a designer is completely achieved, the satisfaction degree is one, and when the aspire is not achieved at all, the satisfaction degree is zero. Evidently,

2: Concept of satisfaction

The most prominent characteristic of a cable-stayed bridge is the introduction of cable prestresses to change the static equilibrium in order to reduce its weight. However, the optimum state of cable prestresses should be determined from various points of view. As well as the weight reduction, easiness of fabrication and construction should be considered. Moreover, various kinds of errors can not be avoided so that the introduction of engineer's knowledge and experience is desirable to derive a practically feasible solution for the determination of cable prestresses. Based upon engineering judgment of a designer, a certain desirable range is first given for each force of structural member. Especially, experienced engineers may provide appropriate desirable ranges with the most desirable values. This desirable range is interpreted in terms of fuzzy sets defined by membership functions[4]. An example of desirable range is presented in Fig. 2, in which F_C is the most desirable value and the values less than F_L and larger than F_U are not accepted. Then, the membership grade corresponds to the degree of satisfaction; 1, 0, and 0 are the degrees of satisfaction for F_C, F_L, and F_U, respectively. Experienced engineers tend to give an F_C value closer to F_U. In this example, F_U, F_L, and F_C are 120 tf, 20 tf, and 100 tf. In this case, it can be said that the designer requires about 100 tf for the prestress of the cable. When 80 tf is obtained as a cable prestress, the degree of satisfaction is calculated as 0.75 from the membership function shown in Fig. 2.

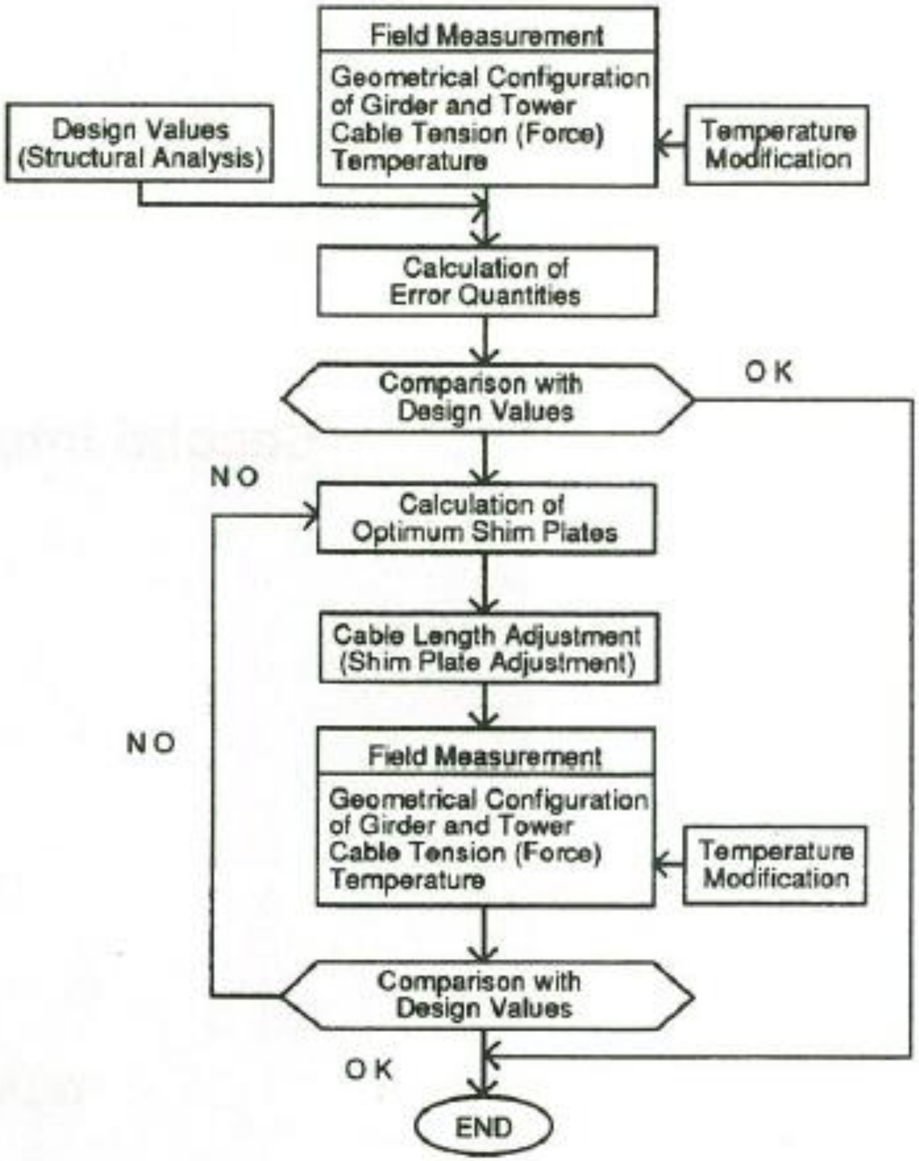


Fig.1 **Management of Erection Accuracy of Cable-Stayed Bridge**

3: Determination of optimum cable prestress using fuzzy mathematical programming

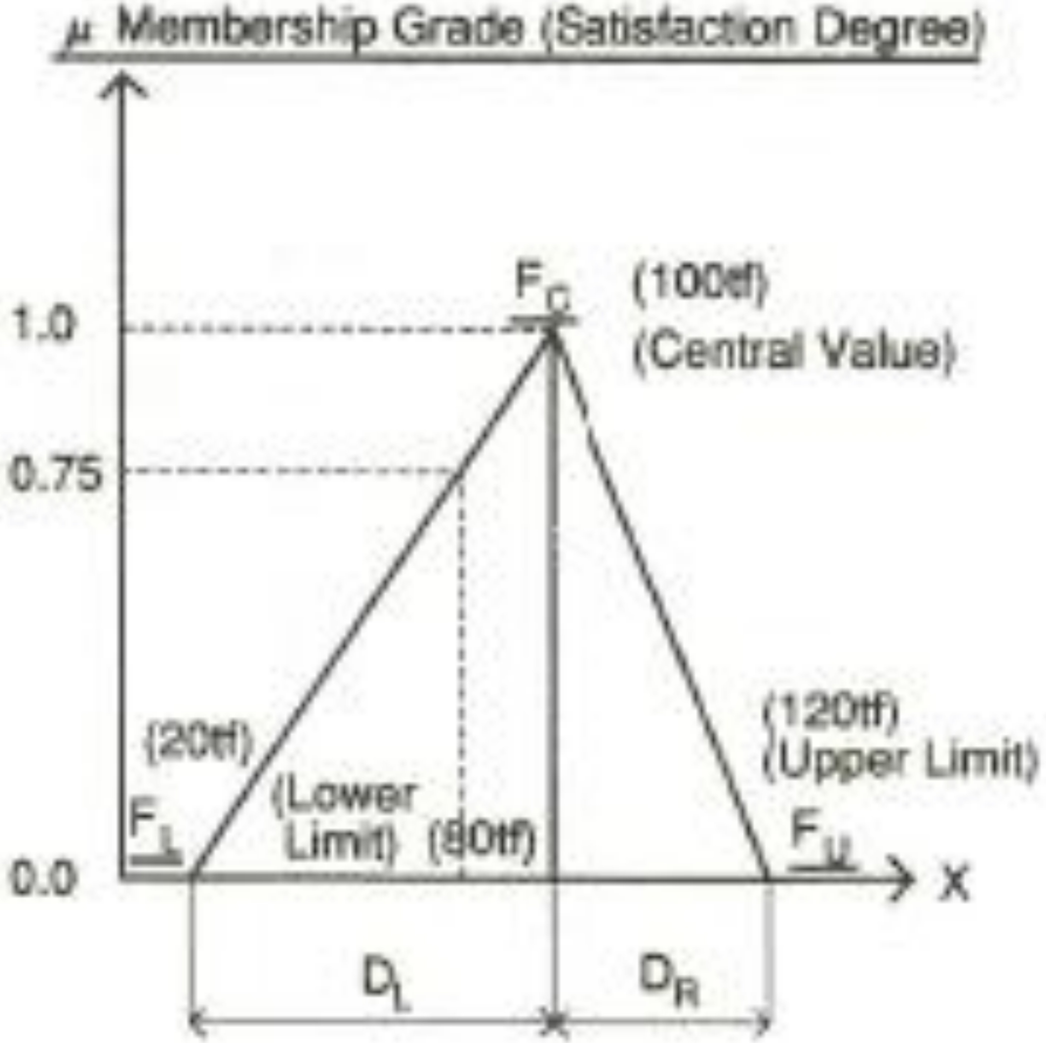
Assuming that the required prestresses are given in terms of fuzzy sets, the problem treated here results in

$$F_{0i} = \tilde{F}_{0i} \qquad (i=1,\cdots\cdots,M) \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

where $\tilde{F}_0$ is the desirable structural member force specified by a fuzzy set. The wave symbol (i.e., ~) indicates fuzzy quantities. M is the number of member forces. Structural member forces after introducing prestresses, F_0, are calculated as follows:

$$F_0 = F_d + \sum_{j=1}^{N} X_i K_{ji} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

where F_d is structural member force due to dead load, X_i is a variable representing cable prestress, and K_{ji} is member force influence coefficient by unit prestress of the cable. N is the number of cables. Fig. 3 shows the flow diagram of structural analysis for cable-stayed bridges.


μ Membership Grade (Satisfaction Degree)
1.0
0.75
0.0
F_C
(100tf)
(Central Value)
(20tf)
(Lower
Limit)
F_L
(80tf)
(120tf)
(Upper Limit)
F_U
X
D_L
D_R

Paying attention to the j-th member force, the following equation is derived from Eqs. 1 and 2.

$$F_{Lj} - F_{dj} \leqq \sum_{j=1}^{N} X_i K_{ji} \leqq F_{Uj} - F_{dj} \qquad \cdots\cdots\cdots\cdots \quad (3)$$

Using the following transformations

$$F_{Lj}' = F_{Lj} - F_{dj} \qquad \cdots\cdots\cdots\cdots \quad (4)$$

$$F_{Uj}' = F_{Uj} - F_{dj} \qquad \cdots\cdots\cdots\cdots \quad (5)$$

the degrees of satisfaction are expressed as follows, for the left-hand side and right-hand side of the central value of the membership function.

For left-hand side

$$\mu_{jL}(u) = \begin{cases} 0.0 \ (u \leqq F_{Lj}') \\ 1.0 - (F_{Cj}' - \sum_{j=1}^{N} X_i K_{ji}) \,/\, D_{Lj} \ (F_{Lj}' \leqq u \leqq F_{Cj}') \end{cases}$$

$$\cdots\cdots\cdots\cdots \quad (6)$$

For right-hand side

$$\mu_{jR}(u) = \begin{cases} 1.0 - (F_{Cj}' - \sum_{j=1}^{N} X_i K_{ji}) \,/\, D_{Rj} \ (F_{Lj}' \leqq u \leqq F_{Uj}') \\ 0.0 \ (u \leqq F_{Uj}') \end{cases}$$

$$\cdots\cdots\cdots\cdots \quad (7)$$

where D_{Rj} and D_{Lj} denote the scatter parameters of right-hand and left-hand sides, respectively.

Here, two kinds of objective functions are employed:

Objective function 1: $\mu_D(u) = \max \{\min (\mu_{1L}(u), \mu_{1R}(u), \cdots\cdots \mu_{mL}(u), \mu_{mR}(u)\}$ ………………………… (8)

Objective function 2: $\mu_D (u) = \sum_{j=1}^{M} \mu_j (u) \rightarrow \max$ …… (9)

The above fuzzy mathematical programming problem consisting of Eqs. 7 (constraints) and 8 or 9 (objective function) can be solved by using a linear programming computer package without difficulty. The problem with Eq. 8 as the objective function is referred to Method 1, whereas the problem with Eq. 9 is referred to Method 2.