A STUDY ON THE LONG-TERM CREEP DEFORMATION OF PC RIGID FRAME BRIDGE WITH CENTRAL HINGE

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Abstract

It has been reported that PC rigid frame bridges with central hinge can experience displacement of the central hinge to a degree that exceeds the deformation predicted at the time of construction. Therefore, this paper provides an analysis to grasp the cause of deviations between the design value and the actual value. The analysis method set up conditions that divided the analysis model into upper slab, web, and lower slab. As a result, when reproductive calculations of the deformation are done over a long period of time, we found mostly good agreement with actual measurements.

1. Introduction

Many PC rigid frame bridges with central hinge were built using the Dywidag method during the 1960’s to 1980’s. This was because the structural design is comparatively simple and construction costs are low. However, since there is a hinge, displacement increases over due to concrete drying shrinkage or even long-term creep deformation. Therefore, there have been reports that the displacement of the central hinge exceeds the deformation and/or deflection predicted at the time of construction.

Hanshin Expressway includes four PC rigid frame bridges with central hinges in its inventory. One, the Kireuriwari bridge, was massively reinforced. Also, the hinge deflection of the Sueyoshi Bridge has progressed beyond the deflection predicted at the design stage. This phenomenon was analyzed and considered as follows.

Differences in shrinkage a appears in concrete of identical composition in different sections such as the upper slab, web, and lower slab of a box girder cross section. This is because sectional curvature can boost the deformation. Therefore in this study, our experimental analysis considered the increase in strain over time for each

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factor of cross-section size, cross-section shape, relative humidity, reinforcing bar and difference in intensity of restraint with PC steel used for upper slab, web, and lower slab. As a result, we found that the deflection value is actually larger than what was predicted in the design. In doing this, we gathered basic data to contribute to future maintenance management.

2. Specifications of the bridge

Table 1 Specifications of the target bridge

Route	Loop Route
Name	Sueyoshi Bridge
Length	L=166.000m （48.000m+70.000m+48.000m）
Width	w=17.000m
superstructure	3 span continuous PC box girder bridge
substructure	rigid frame piers (3), T-type (1)
Foundation	piled foundations (4)
Intersection	Route 308, Higashi Yokobori river

Figure 1 Overview

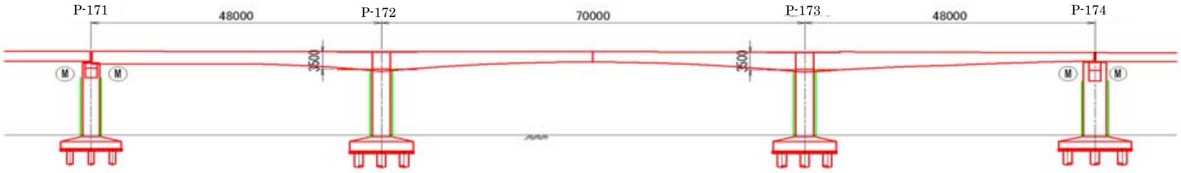


Figure 2 General drawing

3. Reproduction of long-term deflection Using Creep Analysis

3.1 Outline of analysis

This analysis used long-term deformation prediction formulas taken from the Japan Standard Specifications for Concrete Structures – 2012 “Design”. The analytical model divides a box girder section into an upper slab, web, and lower slab. Creep analysis was conducted using this analysis model. The flow chart of a creep analysis is shown in Figure 3.

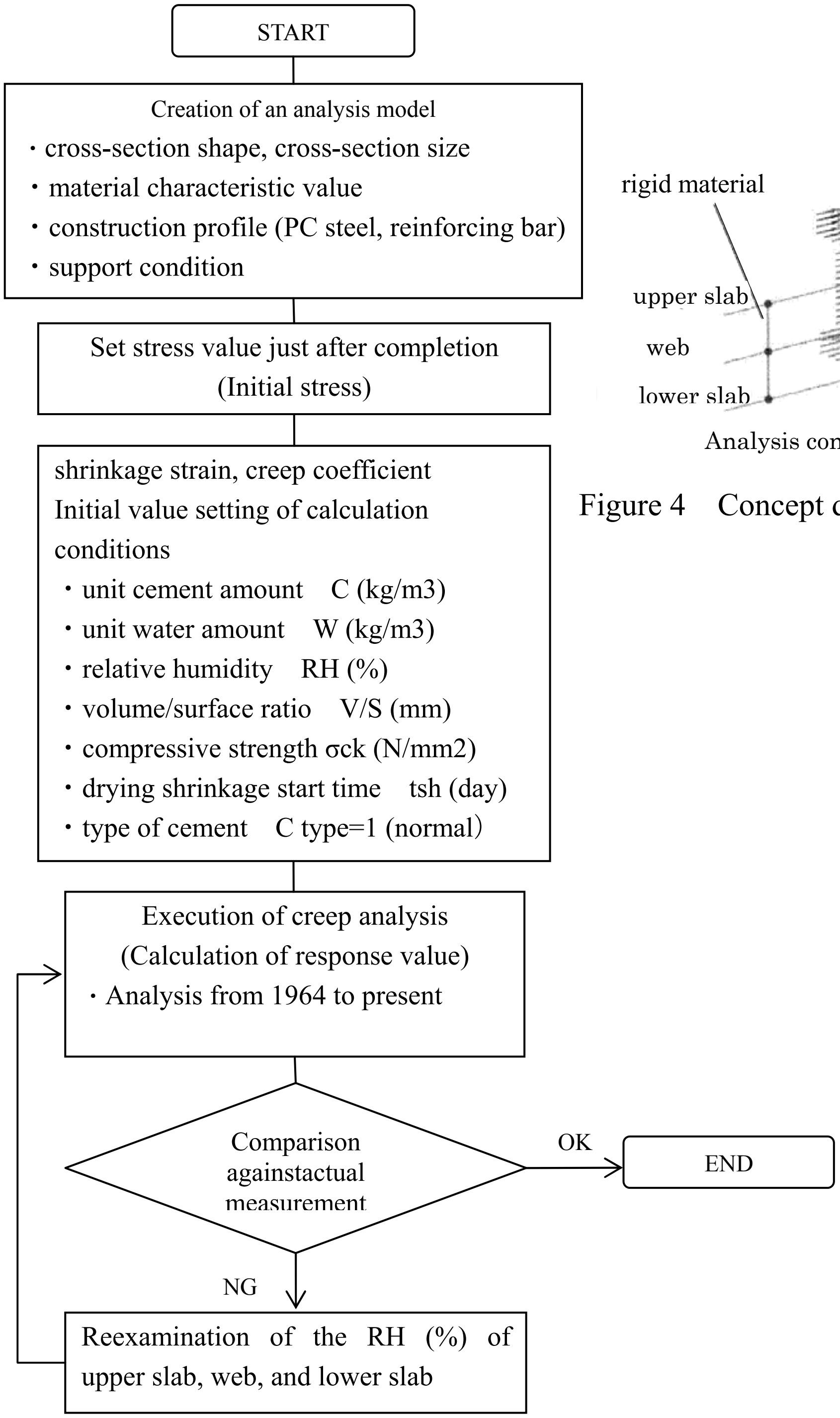


Figure 3 Outline of analysis

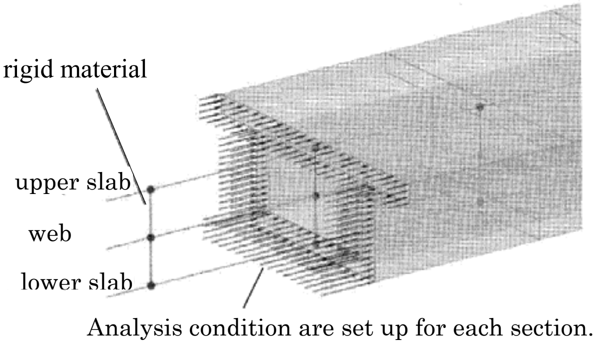


Figure 4 Concept diagram of the analysis model

3.2 Analysis condition

Analysis conditions are shown in Table 2.

Table 2　Analysis Conditions

analytical model	A PC box girder with overhang was modeled. Analytical model divides a box girder section into an upper slab, web, and lower slab and uses this fiber model.(Figure 5)	
materials	concrete	design strength　fck : $40\mathrm{N/mm^2}$ unit cement amount　C : $447\mathrm{kg/m^3}$ unit water amount　W : $170\mathrm{kg/m^3}$ water-cement ratio　W/C : 38%
	PC steel, reinforcing bar	Adopted the value of as-built drawings
environmental condition	Annual average relative humidity:　64% Average relative humidity from 1965 to 2013 (Data of the Meteorological Agency)	
initial sectional force	Long-term Creep Deformation shall be based on the load just after completion. The direct entry of sectional force just after completion computed by design calculation is carried out. The sectional force in that case is shared for each upper slab, web, and lower slab.	
construction schedule	The days of overhang erection were considered. (Figure 6)	

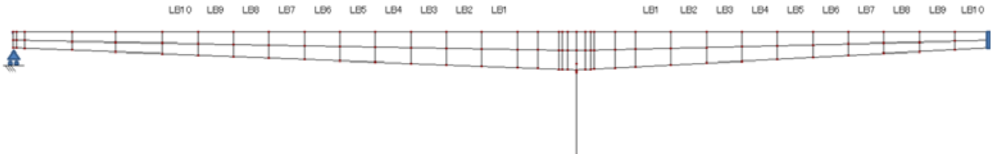
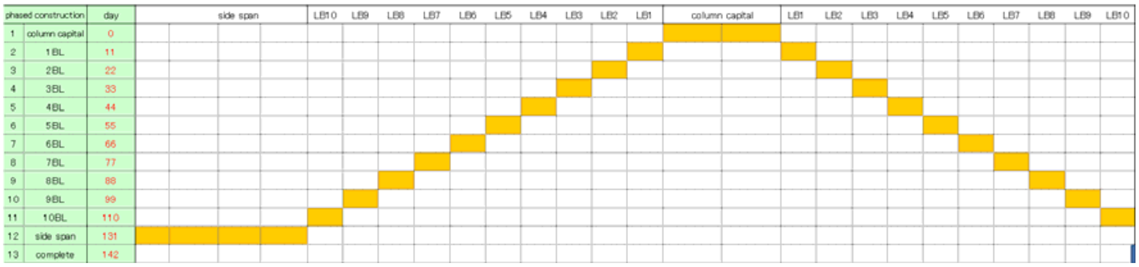


Figure 5　Analytical model



phased construction		day	side span	LB10	LB9	LB8	LB7	LB6	LB5	LB4	LB3	LB2	LB1	column capital	LB1	LB2	LB3	LB4	LB5	LB6	LB7	LB8	LB9	LB10
1	column capital	0												🟨										
2	1BL	11											🟨		🟨									
3	2BL	22										🟨				🟨								
4	3BL	33									🟨						🟨							
5	4BL	44								🟨								🟨						
6	5BL	55							🟨										🟨					
7	6BL	66						🟨												🟨				
8	7BL	77					🟨														🟨			
9	8BL	88				🟨																🟨		
10	9BL	99			🟨																		🟨	
11	10BL	110		🟨																				🟨
12	side span	131	🟨																					
13	complete	142																						

Figure 6　Construction Schedule

3.3 Long-term deformation prediction formula

This analysis targets a calculation of long-term creep deformation. Therefore, we defined the creep coefficient and drying shrinkage progress curve for calculating the long-term creep deformation.

3.3.1 Creep coefficient

Creep factor is calculated by the following formula. (Standard Specifications For Concrete Structures – 2012 “Design”5.2.9 is applied)

$$\emptyset(\mathrm{t},\mathrm{t}') = \frac{4W\left(1-\frac{RH}{100}\right)+350}{12+f_c'(t')}\cdot \log_e(t-t'+1)\cdot 10^{-6}\cdot E_c(t')$$

(formula-1)

t：material age of the concrete at time of focus (day)

t’：material age of the concrete at time of loading (day)

W：unit water amount (kg/m^3)(W≦175kg/m^3)

RH：relative humidity (%)(50≦RH≦80%)

fc’（t’）：compressive strength (N/mm^2) at the age of t’(day)

3.3.2 Drying shrinkage strain

Shrinkage strain at the age of t(day) using the following formula.

$$\varepsilon_s(t) = \varepsilon'_{ds}(t,t_0) + \varepsilon'_{as}(t,t_s) \qquad \text{(formula-2)}$$

$\varepsilon'_{ds}(t,t_0)$：drying shrinkage strain ($\times 10^{-6}$) at the age of t’(day)

$\varepsilon'_{as}(t,t_s)$：shrinkage strain of the concrete of a seal state from a concrete setting time to t

3.4 Creep analytical method

This analytical method evaluations allow consideration of relief from creep to the stress which occurs for every interval. It also considers the includes one by one, the influence of the stress fluctuation with the change of properties of matter, drying shrinkage or curing history, temperature history to calculation. To compute stress and strain is σ(ti+1/2) and ε(ti+1/2) at the time of ti+1/2. Therefore, this yields the following formula.

$$\varepsilon\left(t_{i+\frac{1}{2}}\right)=\frac{\sigma\left(t_{i+\frac{1}{2}}\right)-\sigma\left(t_{i-\frac{1}{2}}\right)}{E(t_i)}\left(1+\emptyset\left(t_{i+\frac{1}{2}},t_i\right)\right)$$

$$+\sum_{j=1}^{i-1}\frac{\sigma\left(t_{j+\frac{1}{2}}\right)-\sigma\left(t_{j-\frac{1}{2}}\right)}{E(t_j)}\left(1+\emptyset\left(t_{i+\frac{1}{2}},t_j\right)\right)+\varepsilon_f\left(t_{i+\frac{1}{2}}\right)$$

(formula-3)

In this analysis, creep analysis used formula-3.

3.5 Analysis result

3.5.1 Shrinkage strain and creeping coefficient

The change of a value to the progress day of shrinkage strain and creeping coefficient is shown in Figure 7 and 8. The shrinkage strain has a larger ratio for large volume/surface than for the small ratio. Creeping coefficient becomes equivalent by all the components. This is because changes in the relative humidity is the same for all materials.

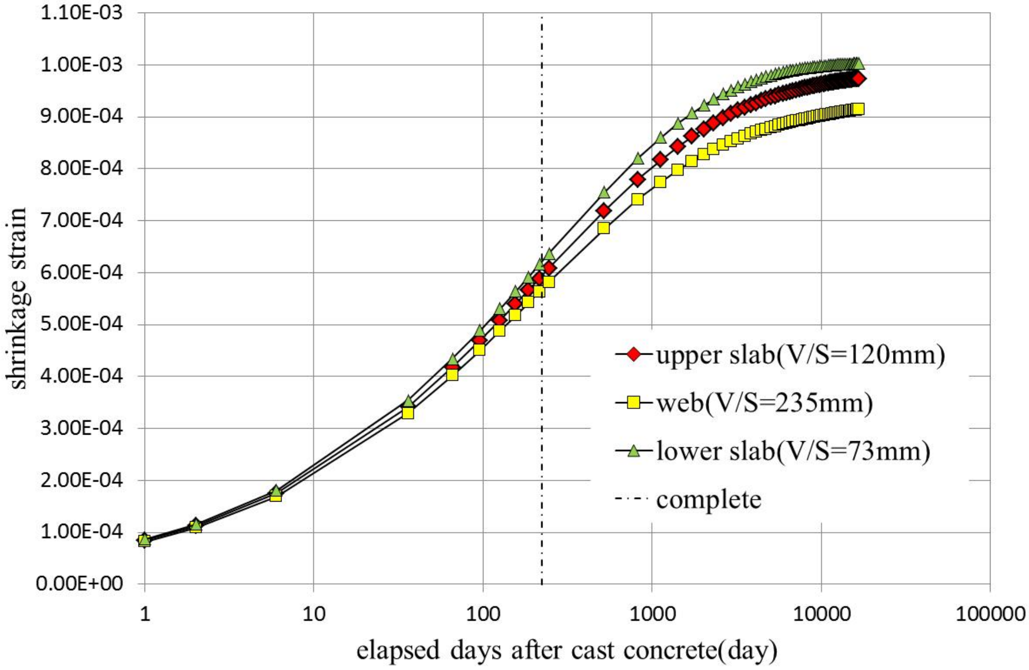


Figure 7 Shrinkage strain

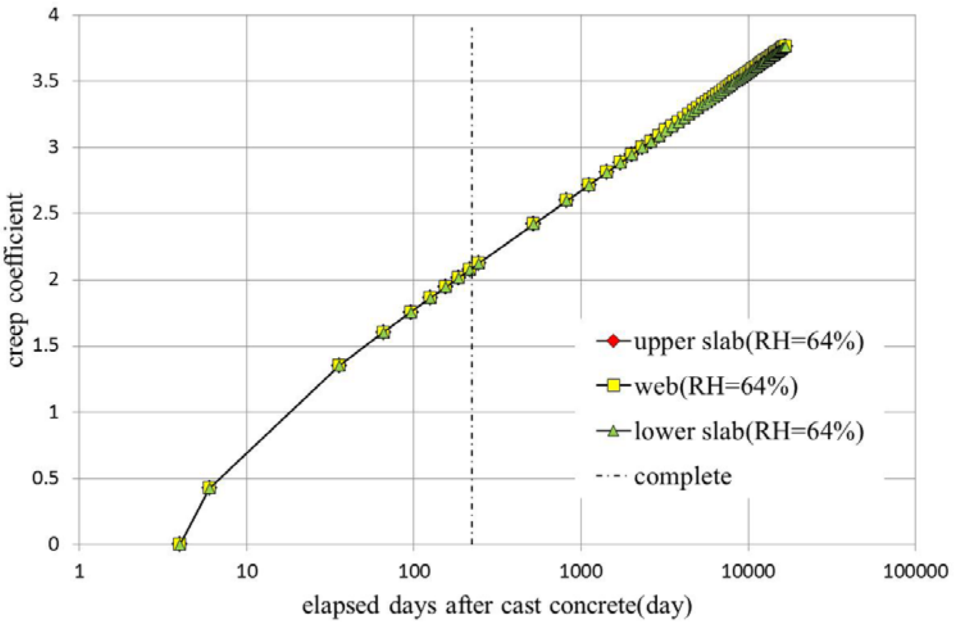
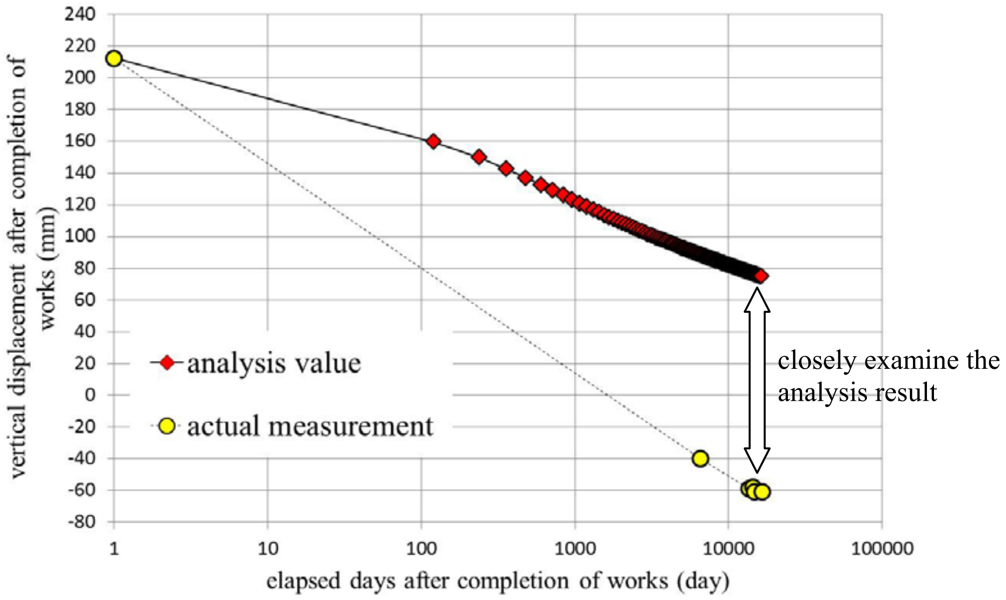


Figure 8　Creep coefficient

3.5.2 Calculation of long-term creeping deformation

The calculation result of long-term creeping deformation is shown in figure 9. An analysis level has a tendency to become the value smaller than the actual value. Therefore, parametric scrutiny is needed for more accurate reproduction of deformation condition.



closely examine the analysis result

Figure 9　Calculation of long-term creep deformation (center hinge)

4. Reproduction of the long-term deflection by the creeping analysis

4.1 How to reproduce

The variable points of analysis conditions is shown in Table 3.

Table 3　How to reproduce

creep coefficient	upper slab : It takes into consideration that moisture supply by rain water is performed. relative humidity : at 95%.　… analysis condition (1)
drying shrinkage strain	According to the Standard Specifications For Concrete Structures – 2012, "In order to set contraction by dryness to 0, relative humidity is set up to 95%."　… analysis condition(2) However, in the Specifications for Highway Bridges, εs0 becomes about ＋5×10-5 with 95% of relative humidity. Therefore, drying shrinkage strain in consideration of the moisture supply by rain water is taken as 20% of drying shrinkage strain progress at 64% of relative humidity (design level).　… analysis condition(3)　(Table 4)
post dead load	Noise barrier and inspection way were built in 1994.
volume/surface ratio	Pavement and bridge surface waterproofing were given to the upper slab. Therefore, the set up notes that only the underneath surface of upper slab is exposed to the air.　… analysis condition (4)

Table 4　Value of εso by the environmental condition

(Specifications for Highway Bridges table-2.2.3)

environmental condition	ε_{s0}
In the water	-10×10^{-5}
RH 90%	$+10\times10^{-5}$
RH 70%	$+25\times10^{-5}$
RH 40%	$+50\times10^{-5}$

4.2 Analysis result

4.2.1 Shrinkage strain and creep coefficient

The change of a value to the progress day of shrinkage strain and creep coefficient is shown in Figures 10 and 11. In drying shrinkage strain, shrinkage strain of the upper slab is small. This is because the floor version was made into about 20% of relative humidity to other parts of 95% of relative humidity. In the creep coefficient, upper slab with high relative humidity becomes a value smaller than others.

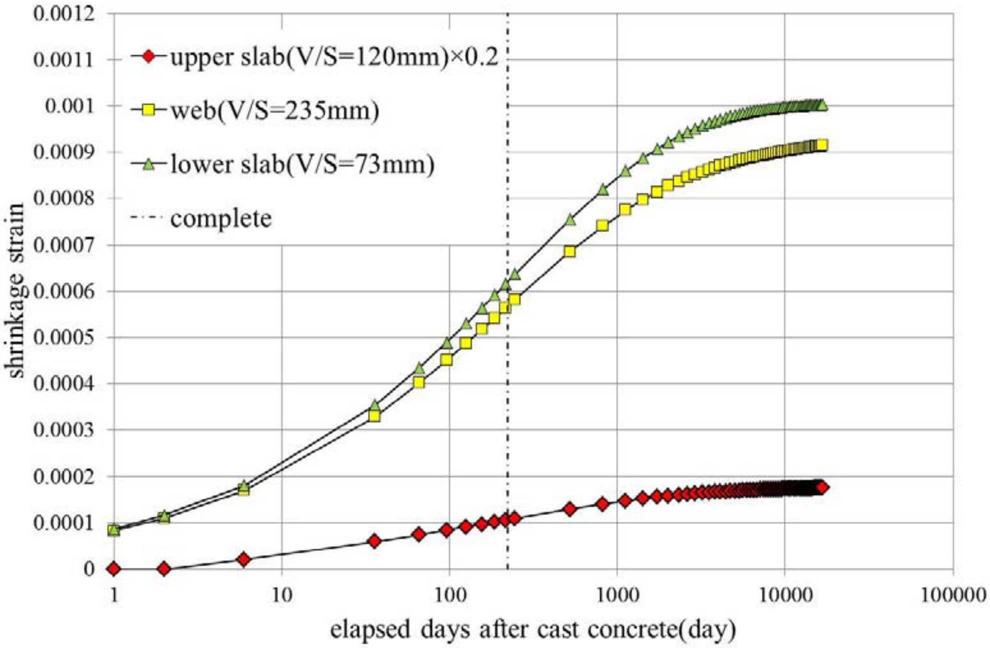


Figure 10 Shrinkage strain

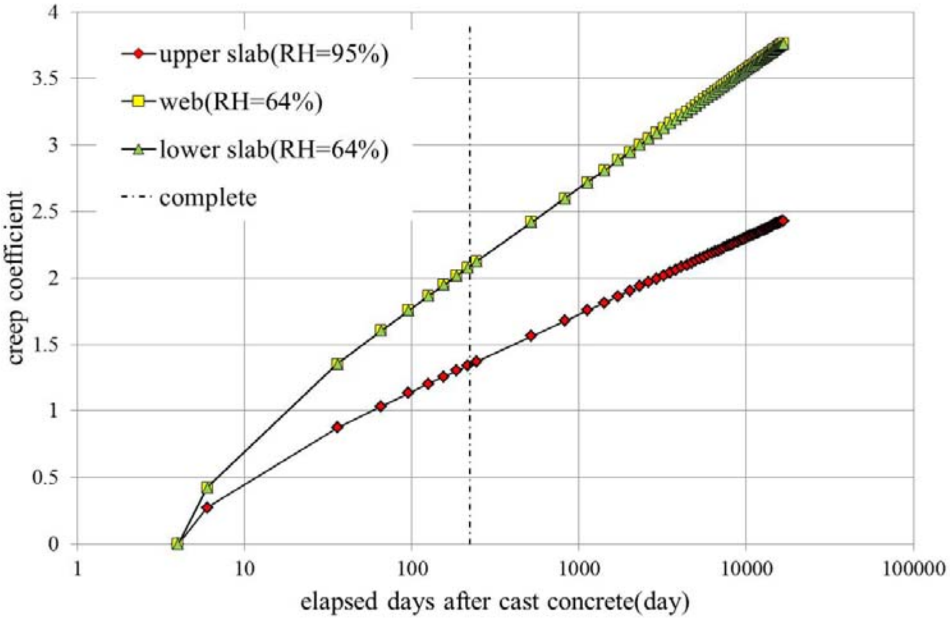


Figure 11 Creep coefficient

4.2.2 Calculation of long-term creeping deformation

The calculation result of long-term creeping deformation is shown in Figure 12. It is a value of the initial analysis and the value that accumulated in each case. This makes it possible to see the effect of the changed parameter.

The results show that the differentiation of post dead load, effective thickness and creep coefficient does not contribute significantly. On the contrary the 20% reduction of drying shrinkage strain in the upper slab influences the most on the differentiation greatly. In addition, vertical displacement exceeded an actual value when assumed the dry shrinkage strain of the upper slab 0 like a condition of Standard Specifications for Concrete Structures – 2012. Present situation reproduction is in this way possible by the analysis that considered a shrinkage difference to each material.

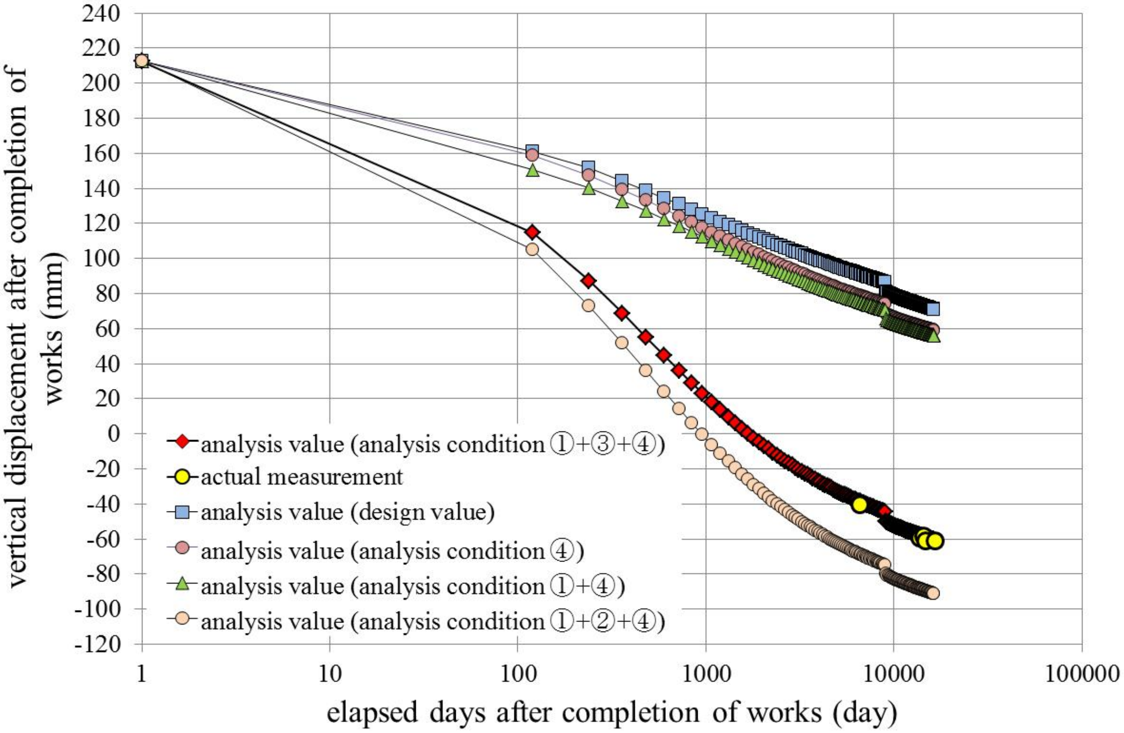


Figure 12 Calculation of long-term creep deformation (center hinge)

4.3 Sensitivity analysis of each parameter

The sensitivity-analysis result of each parameter is shown in Table 5. This result showed that relative humidity greatly influenced long-term Creeping Deformation.

Table 5 Sensitivity analysis of each parameter

parameter	Influence of long-term deformation
Water (W) Cement (C)	water (W) is increase to 200 kg/m3 → increases 7 mm
	water-cement ratio (W/C) is increased to 0.5 → increases 11 mm
relative humidity (RH)	all materials at 95% relative humidity (RH) → decreases about 60 mm
	all materials at 40% Relative humidity (RH) → increases 60 mm
	only upper slab at 95% Relative humidity (RH) → increases 150 mm
volume / surface ratio (V/S)	surface area of inside the box girder web and lower slab is disregarded (increase V/S) → increases 17 mm
	only underneath surface of upper slab is exposed to the air → decreases about 25 mm
compressive strength (σ_{ck})	compressive strength is lowered in 30Ns/mm → increases 30 mm
	compressive strength is upper in 50Ns/mm → decreases 25 mm

5. Future prediction

The creeping deformation analysis result of 100 years later is shown in Figure 13. It is assumed that the deformation appears continuously with age although its quantity remains around 10 mm over time

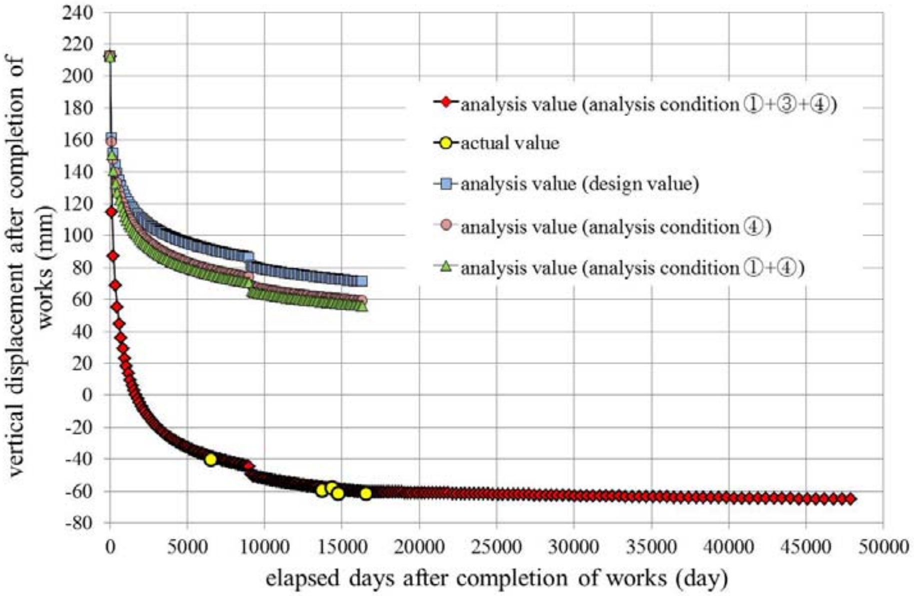


Figure 13 Reproduction of the long-term deflection by the creep analysis (center hinge)

6. Conclusion

Creep analysis conducted with new knowledge was performed on the Sueyoshi bridge. When reproductive calculations of the deformation were carried out for long period of time, we confirmed mostly good agreement with actual measurement findings.

- The deformation continues if long-term deformation prediction formula is used based on Standard Specifications for Concrete Structures – 2012 “Design” from prediction relation used conventionally over an extended period .
- The Analysis model divided box girder sections into an upper slab, web, and lower slab. The deformation in agreement with the actual measurement by the analysis which considered material specific shrinkage differences.
- Pavement and bridge surface waterproofing are applied on the upper slab. Therefore, the upper slab is different from the web and lower slab in environmental condition. By considering relative humidity and volume/surface ratio, the analytical value can obtain the result which is mostly in agreement with an actual measurement.
- In reproduction of the long-term deflection by the creeping analysis , relative humidity (RH) is a dominant factor. Therefore, the accuracy of the relative humidity of each component is important.
- The deformation will continue for the next 100 years and the quantity of the deformation will be around 10mm.