

Effect of Creep on the Long-Term Deflection of Box Girder Balanced Cantilever Bridge Structure Using B3 Model and CEB 2010

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ABSTRACT Creep significantly affects the long-term deflection of the prestressed concrete bridge structure. Some models often used in predicting creep on concrete, such as ACI, AASHTO, and CEB, do not consider the water-cement ratio in the formula. The water-cement ratio is one of a factor in the magnitude of creep. If the water-cement ratio is excessive, the creep will also be significant. B3 Model uses the water-cement ratio in predicting creep in prestressed concrete bridge structures and has provided good accuracy with measured deflection data. This study compares the B3 Model with Model CEB 2010 to predict the effect of creep on long-term deflection. The bridge structure is modeled using Midas Civil 22 v1.2 software in this paper. The envelope displacement of the bridge B3 Model is more significant than CEB 2010. The prediction deflection of the B3 Model in 100 years of service life of the bridge is -16.34 cm, while CEB 2010 is -11.90 cm. Creep affects total deflection by 84% to 88%. Creep affects the deflection significantly because, in the construction process, each box girder segment is stressed and loaded at concrete age of 3 days. At the age of 3 days, the elastic modulus of the concrete is still not reached, and the cement paste on the concrete is still in the hydration process. The results showed a significant difference between B3 Model and CEB 2010. B3 Model predicts that the long-term deflection of the bridge until the end of the bridge's service life is 44% to 49% greater than the CEB 2010 model. The prediction of total deflection until the end of the service life bridge does not exceed the deflection limitation due to dead load determined by the codes of SNI and CEB.

KEYWORDS Creep; Deflection; Long-term; B3; CEB

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1 INTRODUCTION

Long-term deflection investigation of bridges is essential to avoid excessive deflection (Bažant et al., 2012). Several box girder prestressed concrete bridges show excessive deflection (Bažant et al., 2012). According to preliminary studies, a creep causes an increase in the bridge's long-term deflection is a creep (Bažant et al., 2012; Vokunnaya and Tanaji, 2017; Akbar and Carlie, 2021). Loss of prestressing also leads to additional deflection from creep and shrinkage in the long run (Nawy, 2000).

Bridge construction methods significantly affect the long-term behavior of its structure (Vokunnaya and Tanaji, 2017). The free cantilever method is often used to construct prestressed concrete box girder bridges (Akbar and Carlie, 2021). This method is usually very influential in the long term because the tendon stresses on concrete are

still early (Vokunnaya and Tanaji, 2017). When the tendon stressing process early-age concrete, it will significantly impact creep in the long term (Yoon et al., 1999; Giaccu et al., 2021).

Atrushi (2003) stated that creep increased significantly because the concrete at an early age had a low modulus of elasticity and was hydrated. The modulus of elasticity of the design concrete is reached after 28 days. When the prestressed concrete bridge is loaded early, it will affect the creep behavior in the long term (Yoon et al., 1999). Therefore, from this literature, calculating the deflection due to creep in the long term is essential to maintain the structure's stability.

Creep is a strain behavior that increases over time due to a constant load (Nawy, 2000). It is mostly affected due to a significant water-cement ratio

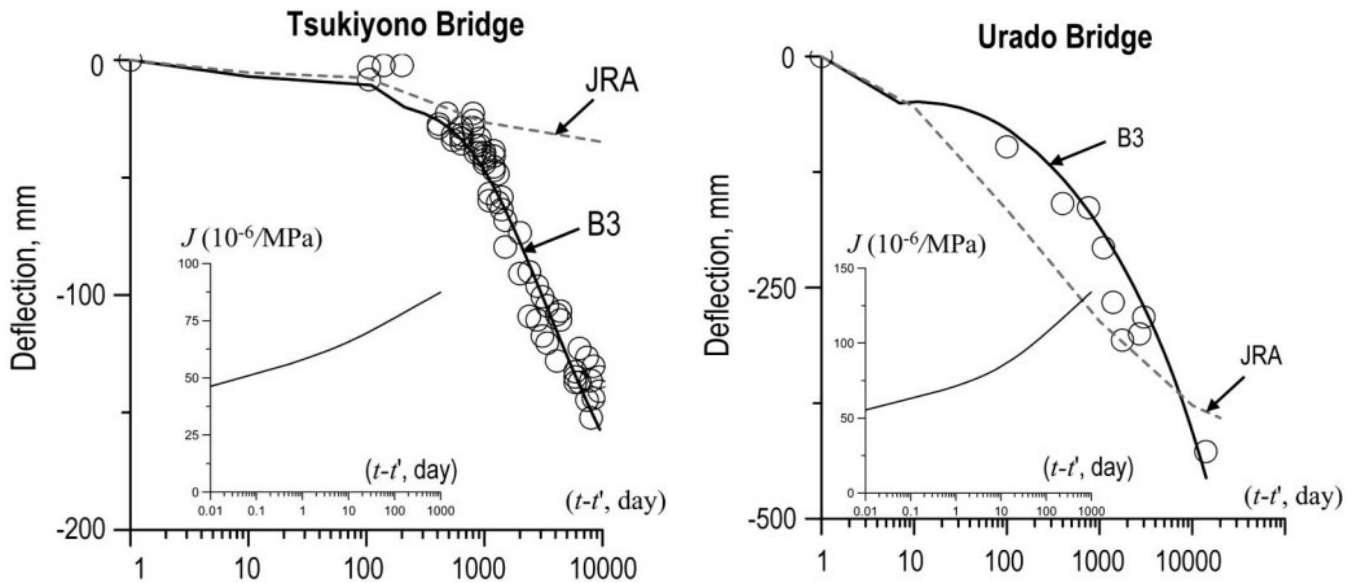


Figure 1. Comparison deflection of B3 Model, JRA model, and measured bridge deflection in Japan (Bažant et al., 2012)

(Bažant et al., 2012; Bazant and Baweja, 2000; Brooks, 2005). Some models used in predicting creep in bridge design are ACI, CEB, European, JSCE, AASHTO LRFD, etc. However, these models do not include the water-cement ratio in calculating their predictions (Committee et al., 2008). According to Bažant et al. (2012), the water-cement ratio is the most influencing factor for creep. Therefore, it is necessary to include the value when predicting the amount using the B3 Model. The CEB 2010 model is the most commonly used bridge design to predict the long-term behavior of prestressed concrete bridges. The B3 Model is commonly used to study the long-term deflection behavior of bridges and has provided significant conformity and accuracy to the measured data (Elbadry et al., 2014)

This model has shown predictions almost identical to the measured data in the field, including the Tsukiyono and Urado Bridges in Japan, as indicated in Figure 1. After 30 years, the Tsukiyono and Urado Bridges showed a deflection of approximately 160 mm, and 450 mm, respectively (Bažant et al., 2012). The circular point, dotted line graph, and the black straight line in Figure 1 represent the measured deflection data, the prediction model recommended by the Japan Road Association, and the B3 Model. Furthermore, the prediction of the B3 Model showed an accuracy similar to the measured deflection up to 30 years. Unfortunately, the prediction of the deflection of the JRA Model is

still a significant underestimate of the measured deflection.

Bažant et al. (2012) studied the long-term deflection of the Koror-Babeldaob prestressed concrete box girder bridge with a total span of 241 m in Palau using the balanced cantilever method. This bridge, which was built in 1977, showed excessive measured deflection by Japan International Corporation Agency after 18 years (Bažant et al., 2012). Figure 2 illustrates some of the model predictions used by Bažant et al. (2012) and the measured deflection performed by JICA and ABAM US. B3 Model set1 and set2 are parameters that fit the planning and test data in the field using a trial and error method for the water-cement ratio parameter (Bažant et al., 2012). The graph of the B3 Model set2 shows the best accuracy results for the measured deflection after 19 years. The deflection graph continued to prediction process for an additional 150 years, despite the bridge's collapse after 19 years of service due to various factors (Bažant et al., 2012). Figure 2 shows that the graph of the B3 Model increased significantly as opposed to other models where the rise was asymptotic.

Elbadry et al. (2014) researched deflection control on box girder prestressed concrete bridges using the B3 Model. In the bridge design, the average creep prediction model, commonly used on a laboratory-tested basis over the long term shows that creep reaches its extreme point after 30 years

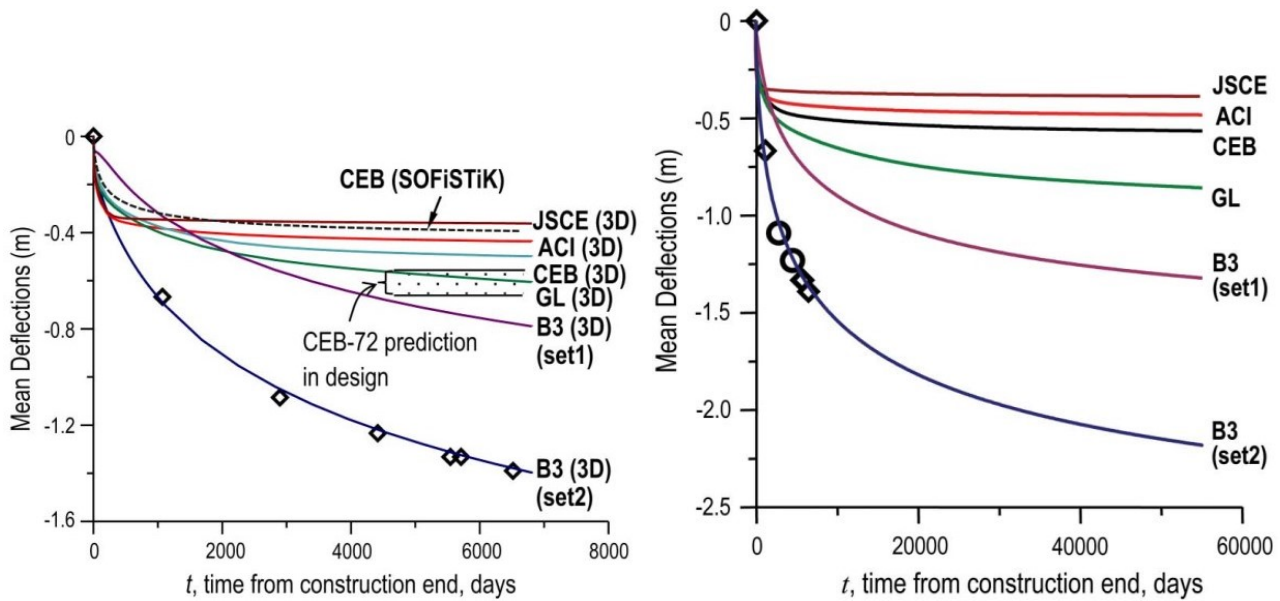


Figure 2. Comparison of the various model's prediction of deflection due to creep and measured deflection (Bažant et al., 2012)

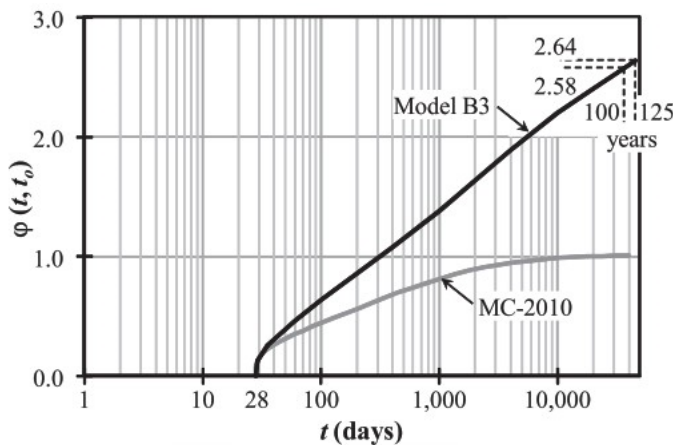


Figure 3. Comparison of coefficient creeps B3 Model with CEB 2010 (Elbadry et al., 2014)

(Elbadry et al., 2014). However, this differs from the B3 Model, which shows unlimited creep prediction with the logarithm of continuous loading days (Elbadry et al., 2014). Figure 3 shows that the creep coefficient on the CEB 2010 model has reached its extreme point, and the graph is asymptotic after 30 years (10 000 days), where the creep coefficient value only is 1. This is in contrast to B3 Model, which shows a very significant increase compared to the CEB 2010 model. In addition, the B3 Model is improving after 30 years because it has not reached its extreme point. The predicted B3 Model value of this creep coefficient is about 2.5 times that of the 2010 CEB MC model.

From preliminary studies, it can be concluded that

the B3 Model shows accurate predictions of creep more significantly than others. CEB 2010 model code bridge design is more significant in predicting creep than other code models.

The B3 and CEB 2010 Models have different approaches to predicting creep in concrete. The B3 Model conducts this process using a complex concrete proportion parameter approach, including water-cement ratio (w/c), aggregate-cement ratio (a/c), cement content (c), and water content (w), as opposed to the CEB 2010. The concrete proportion parameter is the main difference between the B3 and CEB 2010 models. The B3 Model uses complex parameters, while CEB 2010 utilizes simple techniques such as concrete compressive strength, modulus of elasticity, and humidity. The purpose of this study is to compare the prediction of long-term deflection due to creep in box girder bridges with the balanced cantilever cast in situ method using the B3 Model with CEB 2010.

2 METHOD

This study is based on data on bridges that already exist in one of Indonesian cities, which spans across 300 m, at a length and width of 132.5 m and 25.2 m. It is a type of box girder prestressed concrete bridge with a balanced cantilever method of construction. Figure 4 shows that the bridge is modeled using the Midas Civil 2022 v1.2 software with a license obtained by the authors at PT. Mi-

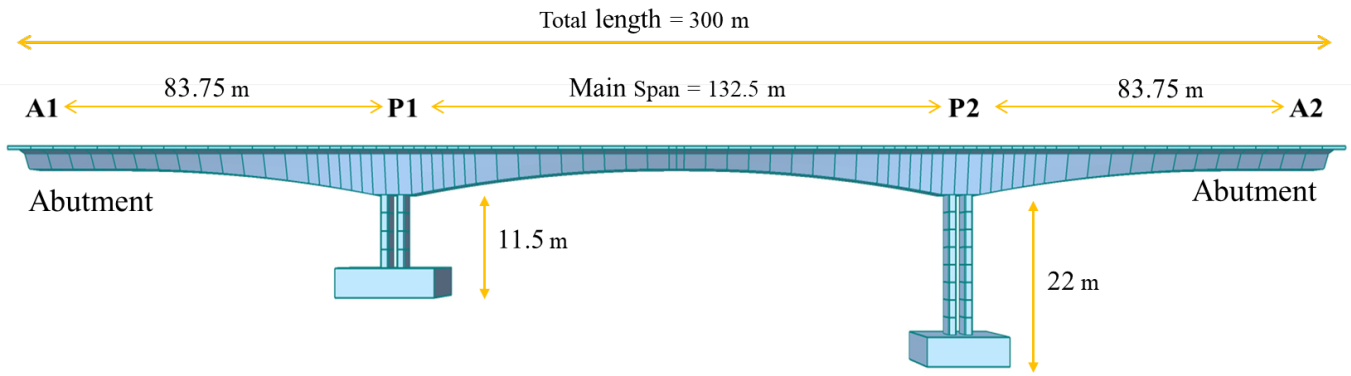


Figure 4. Layout modeling of the bridge after closure in Midas Civil software

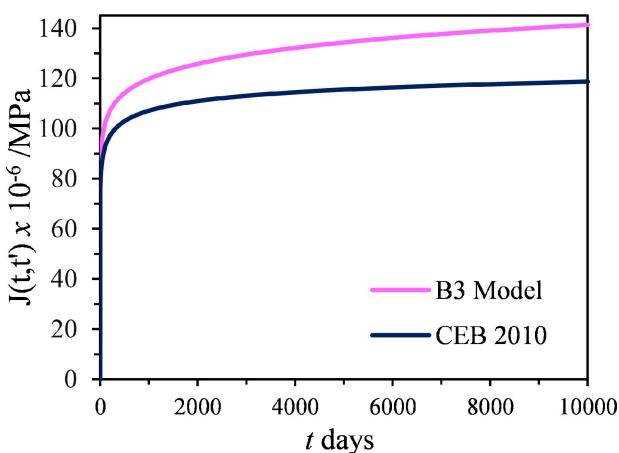


Figure 5. Compliance creeps B3 Model and CEB 2010

dasindo Teknik Utama. The analysis uses the construction stages facility to idealize the balanced cantilever construction method and the creep idealization of the time-dependent bridge structure. The duration of construction stages after completion is 100 years, in accordance with the bridge’s design life. The bridge is modeled with frame elements to idealize its girders, piers, and pile caps. Furthermore, its abutments are idealized as rollers, pile caps, and fixed support. The relationship between piers and bridge girders, as well as piers with pile caps is modeled in the form of rigid elastic links.

The construction duration stage for each segment, and the age at which the concrete is loaded and starts to dry is used by Waskita Karya Inc for construction. In the balanced cantilever stages, the applied load are dead structure, form traveler, construction worker, wet concrete, barrier, and asphalt load. Form traveler load is idealized as a

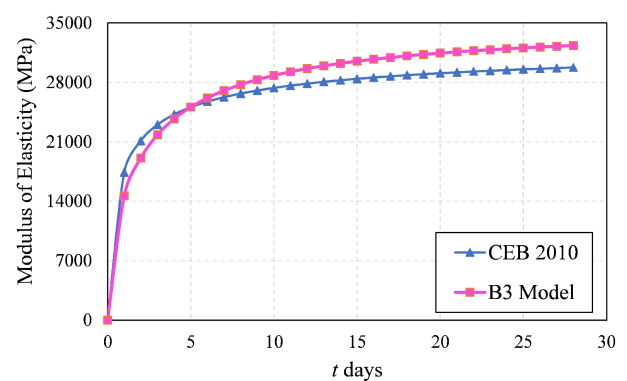


Figure 6. Modulus of elasticity with time graph B3 Model and CEB 2010

point load of 800 kN with the assumption that there is an eccentric force at a moment of 2000 kNm.

The casting was carried out by cast-in-place methods to obtain a wet concrete load during the construction of each box girder segment. This load is idealized with a point in the form of the structural weight of each box girder segment and assumes an eccentricity, hence, there is a moment of 0.5 Ls. The construction worker load is idealized for a uniform load of 2 kNm⁻³. This assumption follows the bridge design using the balanced cantilever construction method recommended by the Midas Civil analysis reference in 2022.

The barrier load of 24 kNm⁻³ with 22 kNm⁻³ asphalt affects the creep. The creep analysis was carried out using the prediction of the B3 Model with CEB 2010. Water-cement ratio of 0.4 started drying the age of concrete in three days (Waskita Karya Inc, 2011), at a humidity of 72% (Niken et al., 2018).

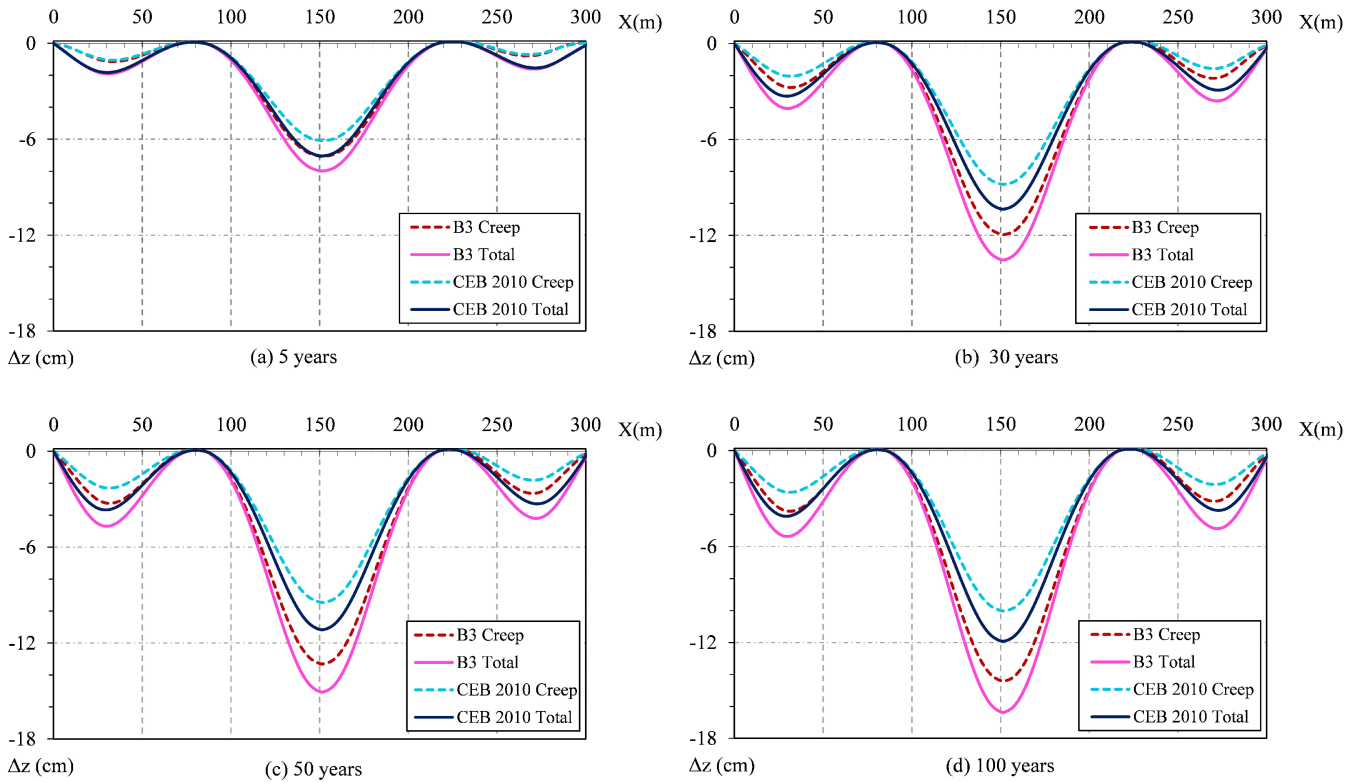


Figure 7. Comparison envelope displacement of bridge B3 Model with CEB 2010 in (a) 5 years, (b) 30 years, (c) 50 years, and (d) 100 years

Figure 5 depicts a graph of compliance creep, which is applied to the concrete age for three days when multiplied by the stress in MPa to produce the creep strain. After 30 years, the B3 and CEB 2010 Models predict compliance creeps of $141.40 \times 10^{-6}/\text{MPa}$ and $118.78 \times 10^{-6}/\text{MPa}$, respectively. The result showed that the prediction of the B3 Model for 30 years is 19% greater than CEB 2010. Figure 6 shows the correlation between the B3 Model and CEB 2010 modulus of elasticity prediction with time. The Midas Civil software entered the parameter compliance creep and modulus elasticity into the user-defined facility. Relaxation of prestressed tendons was considered using the CEB 2010. The total deflection of the bridge in the long term is due to creep and relaxation of the prestressed tendon.

The steps in obtaining the deflection from the software are as follows:

1. Model the bridge in the software.
2. Calculate the predicted creep strain using the formula recommended by the B3 and CEB 2010 Models using the parameters of the concrete characteristics and calculate the creep strain in both models input to the software.

3. Define the time load on the software using the analysis of construction stages with a time load of 100 years.

4. Run the software to show the deflection.

This study has several limitations, such as collecting data on concrete compositions of water, cement, and aggregate contents, as well as the water-cement ratio obtained from primary data. These data referred to Gamnitzer et al. (2019), where the experimental concrete compressive strength value was used to determine the bridge existing data. There are fin stiffeners on the box girder web, hence, the stiffeners cannot be modeled because the software uses frame elements.

3 RESULT AND DISCUSSION

This section discussed the Midas Civil software analysis results of the creep effect on a deflection. The B3 and CEB 2010 models were used to predict the displacement due to creep at the final stage of construction at -45 mm and -33 mm, respectively. The predictions did not show a significant difference at the construction stage. Creep displace-

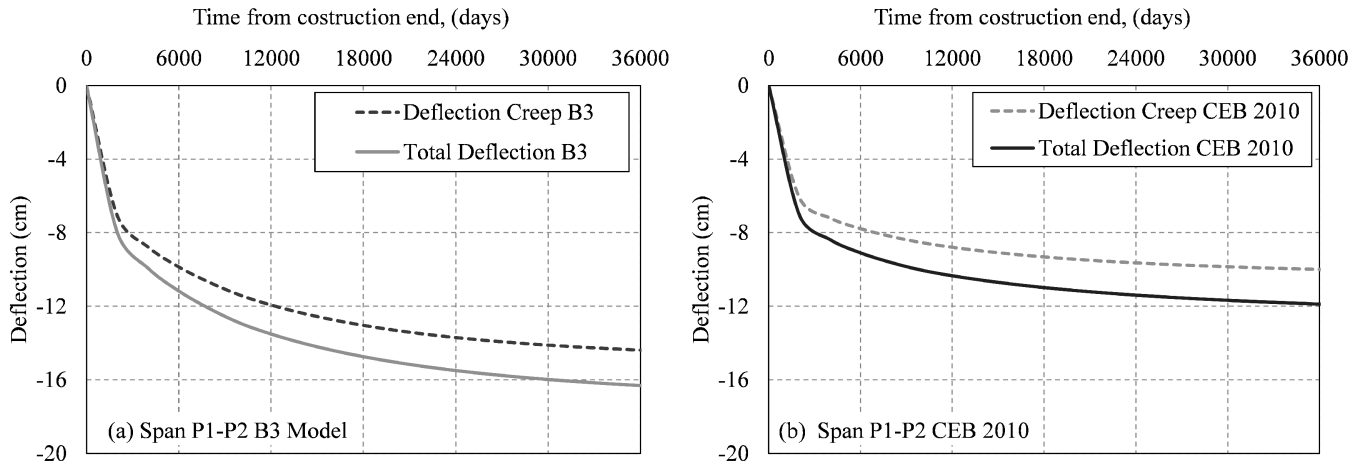


Figure 8. Deflection graph with a time of bridge in main mid-span P1-P2 with B3 Model and CEB 2010

ment is calculated for the camber of the bridge designed at the construction stage, and after closure, it becomes zero.

3.1 Envelope Displacement of Bridge

Figure 7 shows that the envelope displacement z-axis (Δz) graph spans across A1-P1 x-axis 0 - 83.75 m, P1-P2 83.75 - 216.25 m, and A2-P2 x-axis 216.25 - 300 m. The comparison graph of the displacement of the B3 and CEB 2010 models shows different displacement behavior in the mid-span of the P1-P2, as indicated in Figure 10. This starts from the bridge construction (closure) to the end of its service life of 100 years. Maximum displacement is in the mid-span of P1-P2. Furthermore, the prediction process carried out using the both models shows a significantly different envelope displacement graph from 10 to 100 years of bridge service life, as indicated in Figure 7. The maximum displacement for ten years of bridge life predicted by the B3 Model is -7.98 cm with a creep displacement effect of -7.06 cm. At the end of the 100-year service life of the bridge, B3 obtained a maximum displacement of -16.34 cm with a creep displacement effect of -14.40 cm, which increased to -7.34 mm. The CEB 2010 model predicts the maximum creep displacement for 10 years is -7.04 cm with an effect of -6.09 cm. At the end of the 100-year service life, a displacement of -11.90 cm and -10 cm were obtained. Therefore, the creep displacement increases by -2.96 cm in 10 years. The increase in the displacement value of the B3 Model from 10 to 100 years is 1.5 times more significant than CEB 2010. This difference showed

that B3 Model is more significant in predicting the end of the service life of the bridge.

B3 Model predicts that the displacement in 10, 30, 50, and 100 years are -7.97 cm, -13.51 cm, -15 cm, and -16.34 cm, respectively, while CEB predicts -7.035 cm, -10.35 cm, -11.14 cm, and -11.90 cm. The creep B3 and CEB models affect total displacement by approximately 88% and 84%, respectively.

3.2 Deflection Span P1-P2

Figure 8 shows that the comparison graphs of the deflection of B3 Model and CEB Creeps are different in behavior at a mid-span of P1-P2 from the beginning to the end of the bridge's service life of 100 years. Total deflection B3 Model shows a linear graph until 4000 days or 11 years with a deflection of -9.93 cm. Meanwhile, total deflection CEB 2010 shows a linear graph until 2000 days or 5.5 years with a deflection of -8.38 cm. After the asymptotic graph, the deflection total of the B3 Model continues to grow with a more significant increasing slope graph than the CEB 2010. Mid-span total deflection after 36500 days (100 years) for B3 and CEB 2010 Models are -16.34 cm and -11.90 cm. The total deflection of both models does not exceed the dead load permit limit CEB 2010 L/250 or SNI L/300 codes. Therefore, until the end of the service life, the bridge is still in a safe condition.

Figure 8 shows that the creep B3 and CEB 2010 models are the most dominant influence on the long-term deflection of the bridge. The prediction

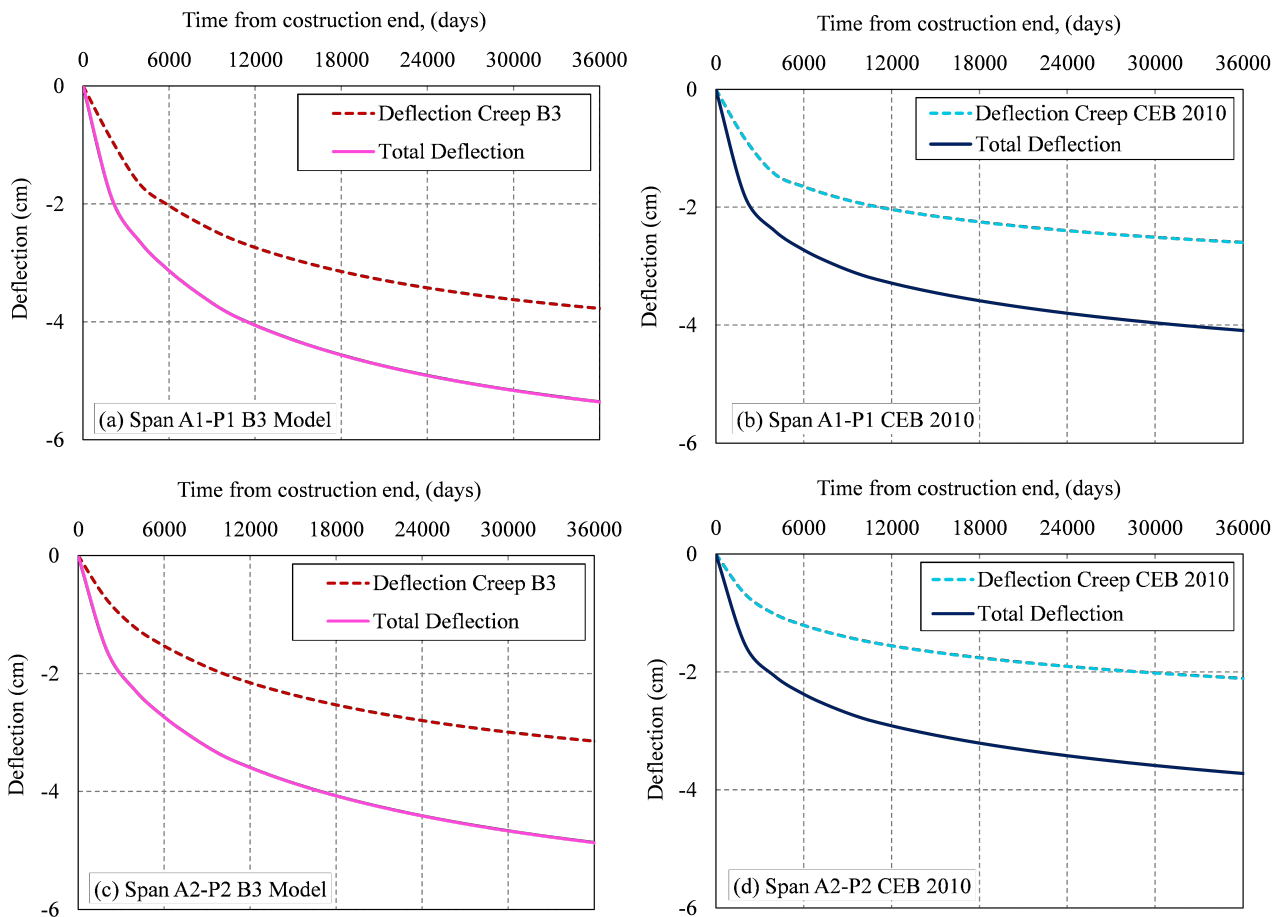


Figure 9. Deflection graph with time in span A1-P1 and A2-P2 with B3 Model and CEB 2010

of deflection due to creep B3 Model 5.5 in the first year of bridge life is -7.0 cm, while CEB 2010 is -6.1 cm. The first 2000 days, or 5.5 years after the bridge was completed, showed significant creep behavior because each concrete segment experienced stress and loading at three days old. According to Yoon et al. (1999), stressed and restrained bridge structures should not be less than three days old. The concrete is still in the hydration process, and the modulus of elasticity is not fully in early concrete, hence, the creep will increase significantly. The creep deflection increases linearly in the first 2000 days, as shown in the previous compliance creep graph. Therefore, it can be concluded that the behavior of compliance creep with deflection is almost the same. After 2000 days, the creep behavior started showing a nonlinear graph where the increase was not as significant as in the beginning. However, the B3 Model still showed a more significant increase than CEB 2010. After 100 years, the deflection due to creep B3 and CEB 2010 models reached -14.4 cm (88%) and -10 cm (84%).

3.2.1 Deflection Span A1-P1 and A2-P2

Figure 9 shows that the total deflection of the B3 Model in 100 years of service life is -5.37 cm in span A1-P1 and -4.90 cm in span A2-P2 with the effect of creep deflection of -3.78 cm and -3.16 cm. Similarly, CEB 2010 predicts the total deflection in spans A1-P1 and A2-P2 of -4.10 cm and -3.73 cm, respectively, with the effect of creep deflection of -2.60 cm and -2.11 cm. Up to 100 years of creep affects the total deflection by 57% to 70% in spans A1-P1 and A2-P2 for both models. Creep B3, and CEB 2010 models dominate the long-term deflection of the bridge in spans A1-P1 and A2-P2, which is accumulated due to loss of prestressing and creep. However, the most significant influence on long-term deflection is creep. Both models predict that the total deflection in spans A1-P1 and A2-P2 will not exceed the allowable deflection limit due to dead loads under SNI L/300 and CEB L/250 codes. The long-term deflection of this bridge is in a safe condition until the end of service life.

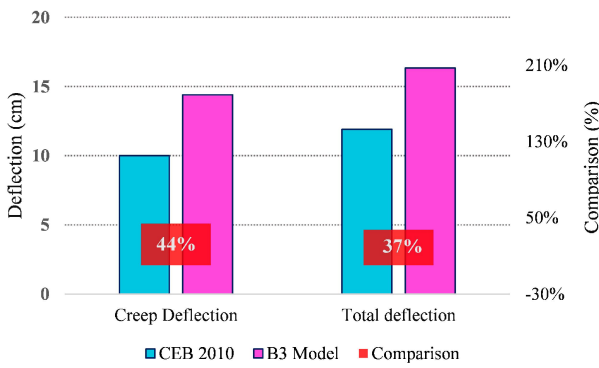


Figure 10. Comparison deflection graph B3 Model with CEB 2010 in span P1-P2

3.3 Comparison prediction B3 Model with CEB 2010

Figure 10 shows a comparison graph of the predicted deflection of the B3 Model with the CEB 2010 spans P1-P2. The predicted and total deflection due to the creep B3 Model is 44% and 37% more significant than CEB 2010, respectively. Bažant et al. (2012) stated that the prediction behavior of the B3 Model was very extreme until it exceeded the deflection permit limit. However, in this study, it is not as extreme compared to the prediction of loss of prestressing by Bažant et al. (2012), which reached 50%. The prediction of loss conducted using CEB 2010 only showed a prestressing loss of approximately 20%. The total deflection in spans P1-P2 does not exceed the permissible limits of SNI L/300 and CEB L/250. The B3 creep prediction model is acceptable according to Committee et al. (2008), because the B3 Model capability of predicting the deflection is still within the allowable limits.

Figures 11 and 12, show that the predicted deflection due to the creep B3 Model is 45% more significant than CEB 2010 in spans A1-P1 and 49% in spans A2-P2. Furthermore, total deflection of the B3 Model is 31% more significant than CEB 2010 in spans A1-P1 and A2-P2, as shown in Figures 6 and 7. The predicted total deflection of both models in spans A1-P1 and A2-P2 also do not exceed the permitted limit for SNI L/300 and CEB L/250 codes.

In the previous literature, the B3 Model showed more significance in predicting deflection, up to 1.3 - 2 times greater than CEB 2010. This study also showed that B3 Model deflection behavior is more significant by 1.42 times greater than CEB 2010. According to preliminary studies, the be-

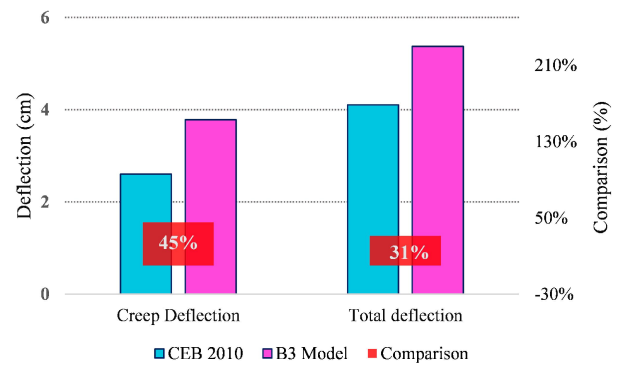


Figure 11. Comparison deflection graph B3 Model with CEB 2010 in span A1-P1

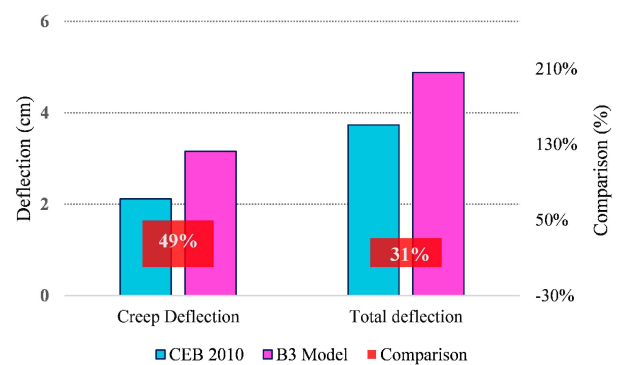


Figure 12. Comparison deflection graph B3 Model with CEB 2010 in span A2-P2

havior of B3 is likely to show a significant increase up to 150 years (Bažant et al., 2012; Elbadry et al., 2014). However, this seems impossible because, according to AASHTO LRFD, the end of the service life of the bridge is only up to 100 years.

The significant difference between B3 Model and CEB 2010 showed that the water-cement ratio parameter is very influential. This is in accordance with Bažant et al. (2012) that the water-cement ratio is essential for predicting creep while CEB 2010 does not consider it, hence, the difference between the two models is significant.

4 CONCLUSIONS AND RECOMMENDATIONS

The total deflections for B3 and CEB 2010 models after 100 years of service life are -16.34 cm and -11.90 cm, respectively. At the end of the service life bridge, B3 predicts deflection due to creep by 88% in the mid-span of P1-P2, while the CEB 2010 is 84%. Creep affects the deflection significantly because stress and restraint are applied to early-age concrete. The construction method of

balanced cantilever cast in situ stressing and loading on the concrete is still at an early age as long as the displacement and stress do not exceed the code permit limits. It can be concluded that the influence of creep dominates in the long-term deflection.

The B3 Model deflection prediction is 44% to 49% more significant than the CEB 2010. Furthermore, the graph of B3 seems more extreme than CEB 2010, which reaches an extreme point after 30 years (Elbadry et al., 2014). The B3 Model showed a slope graph that gives an infinite increase in creep with time. Bažant et al. (2012) stated that the water-cement ratio is essential to predict creep. The main reason the B3 Model with CEB 2010 is significantly different is the water-cement ratio, which is not used by CEB 2010. According to Committee et al. (2008), the significant behavior of B3 is acceptable because it has given good accuracy results to the experimental data owned by the RILEM data bank. Prediction deflection of the model is still within reasonable limits because it does not exceed the allowable deflection limit due to dead load SNI and CEB codes. From ACI's comment, previous literature, and this study's results, it is concluded that the B3 Model can be used to consider long-term deflections in pre-stressed concrete bridge structures. Suggestions to provide more convincing reasons for using the B3 Model to predict creep deflection on the existing bridge are necessary by comparing the measured deflection in the field as stated by Bažant et al. (2012).

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author.

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