Load and Capacity Evaluation of 32 Meters Prestressed Concrete I-Girder

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ABSTRACT
Design methods of a civil structure are continuously improved to keep up with the building technology. One aspect of design methods evolution is a change in the codes or regulation which regulates structural safety to achieve the desired performance. This paper investigates the implication of the new load regulation (SNI-1725-2016) to the structural capacity of a single prestressed concrete I-girder (PCI Girder) with a span of 32 meters. The numerical analysis in this paper was carried out on CSI bridge software to model a single girder with 32 meters of span and 1,6 meters of height. The transfer of prestressed force on the girder is provided by a-high strength strand embedded in 54 MPa of concrete. The analysis showed that a single PCI girder sustained an ultimate flexural loading (*Mu*) of about 11,83 kNm and, at the same time, provided a 13,5 kNm of flexural capacity (*Mn*). Based on the result, it is concluded that applying a new loading rule to a single PCI Girder does not affect the capacity requirement.

Keywords: *code, load, capacity, girder*

1. INTRODUCTION

In recent years, concrete bridge technology developed rapidly with the invention of the prestressed concrete (PC) system. The PC system allows the bridge to increase its spans with less weight, using a prestressed reinforcement strand rather than a reinforcement steel bar. The prestressed action is transferred to the bridge through the strand installed as a reinforcement bar.

Along with the bridge technology development, the design methods also improved, including the change of regulation related to the loading standard of a bridge. In Indonesia, a standard loading regulation was known as RSNI T-02-2005, updated with SNI-1725-2016. The update of standard loading regulation then creates the possibility of design load differences on an existing bridge built before 2016. That design load difference affects the bridge's structural safety regarding the adequacy of the bridge's capacity to carry the design load.

Several papers have discussed the effectiveness of PCI girder. Ikhsan et al [1] found that prestressed concrete I-girder (PCI girder) could substitute the ordinary T girder on Mesekom Bridge, Kalimantan. A PCI girder could increase the clearance under the bridge, which eases the ships passing the river. The PCI girder with a 5351 kN of prestressed force could be efficiently used in 24 meters bridge. The force was transferred using three parabolic tendons of 12 multistrand wires with 12,7 mm diameters [2]. Sari et al [3] has redesigned the 72-meter culvert using 45,8 meters of a span of PCI girder. The PCI girder successfully replaced the culvert system and maintained the city drainage system installed under the bridge. Manalip & Handono [4] has optimized the efficient PCI girder height with various bridge span (20, 30, and 40 meters). It has been found that the optimum girder height for 20, 30, and 40 meters bridges consecutively is 0.9 meters, 1.36 meters, and 1.74 meters. Ismau et al [1] have compared the design load of a PCU-girder according to the RSNI T-02-2002 with SNI 1725-2016. CSI bridge software was used in the paper to model the PCU girder. Ismau et al ET found that the SNI 1725-2016 produced a lower shear force, flexural moment, and deflection than the RSNI-T02-2002.

The previous paper shows that the PCI girder has been widely studied and proven as a bridge's primary structure due to its effectiveness compared to an ordinary concrete girder. However, loading standard regulation changes on a bridge's capacity have not been widely studied, especially for PCI girders. Thus, this paper aims to investigate the implication of a new standard load regulation (SNI 1725-2016) to the structural capacity of an existing PCI girder bridge built before 2016

2. METHODS

The girder data in this paper is provided by PT. Abipraya Beton (Plant Gempol) from a toll road construction project in East Java, Indonesia. The girder has a span of 32.65 meters, and the girder height is 1.60 meters. The girder was constructed segmentally, and the stressing phase carried on using post-tensioned methods after the concrete reached 60 MPa of strength. The prestressed force was transferred through four tendons consisting of 12.7 mm diameters of the strand with an ultimate tensile strength of 18.768 kg/cm2. Generally, the strand is categorized as uncoated stress relief seven wires strand, which complies with ASTM A416. The detail of cross-section and tendon arrangement showed in Figures 1 and 2.

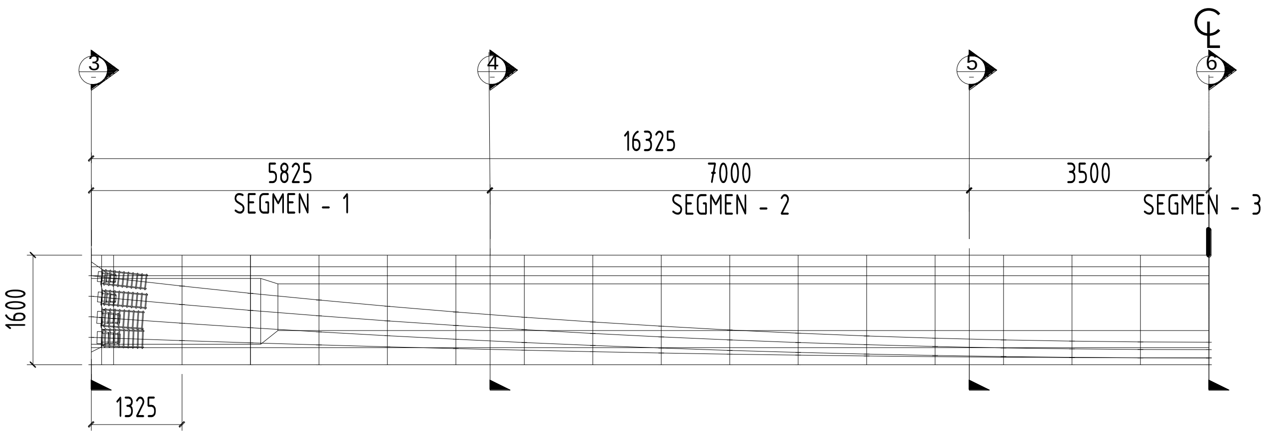

Figure 1. Tendon arrangement along the girder span

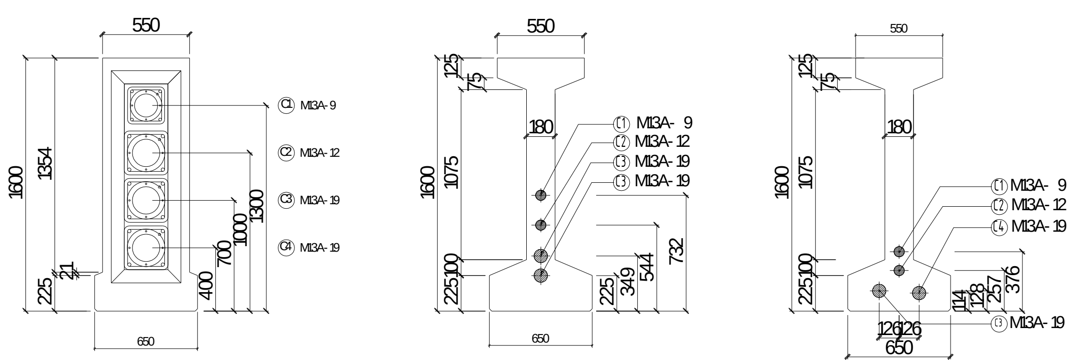

Figure 2. PCI-girder cross section at the end of segmen 1, 2, and 3

The analysis started with modelling the PCI girder on CSI bridge software, followed by the input of material and design load data. The calculated design load was developed based on the bridge geometry and loading condition based on SNI 1725-2016. The analysis then carried on to simulate the loading condition, including prestressed force (PR), structural dead load (MS), additional dead load (MA), braking action (TB), vehicle load (TD), wind load (EW), temperature effect (ET), and earthquake (EQ). The ULS (ultimate limit state) loading combinations (Table 1) were used to identify the ultimate design load working on the PCI girder. Ultimate Limit State (ULS) output parameters were observed, including mid-span displacement, bending moment (*Mu*), and compression stress on the top and bottom fibre of concrete cross-section. All the parameters mentioned then being compared to the limit value to check the fulfilment of the capacity requirement.

Table 1. Ultimate limit state (ULS) loading combination

Load Type	load factor	Comb 1	Comb 2	Comb 3	Comb 4	Comb 5
Structure dead load (MS)	1.2	✓	✓	✓	✓	✓
Additional dead load (MA)	2.0	✓	✓	✓	✓	✓
Vehicle load (TD)	1.8	✓	✓	✓	✓	
Brake load (TB)	1.8	✓	✓	✓	✓	
Wind load (EW)	1.4			✓	✓	
Temperature effect (ET)	1.2		✓		✓	
Earthquake (EQ)	1.0					✓
Prestressed force (PR)	1.0	✓	✓	✓	✓	✓

3. RESULTS AND DISCUSSION

SNI 1725-2016, as a standard loading regulation in Indonesia, has determined the type of load and the procedure to determine the design load on a specific bridge structure. It is known that the load type that must be incorporated into the design load calculation includes dead load (MS and MA), live load (TD and TB), wind load (EW), environment load (ET and EQ) and prestressed load (PR). Each design load is distributed to the bridge structure through three types such as Q (uniformly distributed to the slab), P (point load), and M (bending moment to the girder). The calculation obtained the design load as displayed in Table 2.

Table 2. Design load according SNI 1725-2016

Load Type	Code	Q	P	M
		kN/m	kN	KN.m
Structural dead load	MS	10.50	-	-
Additional dead load	MA	13.42	-	-
Vehicle load	TD	15.54	123.48	-
Brake load	TB	0.95	-	87.05
Wind load	EW	5.09	-	49.24
Temperature effect	ET	-	-	95.81
Earthquake	EQ	1.36	-	-
Prestressed force	PR	-	7301.25	-

As shown in Table 2, the most dominant uniformly distributed load is dead-load, consisting of MS and MA (23.92 kN/m in total), followed by vehicle load (15.54 kN/m). The prestressed forces have the most significant value for the point load because the force was used to stress the tendon that acts as a backbone of the entire structure. Once the prestressed tendons fail, the entire structure will be lost its rigidity and load-carrying capacity.

PCI girder commonly stayed on an ERB (elastomeric rubber bearing) at the end of both sides, making the simple beam assumption relevant to that structure. Thus, all the design loads in Table 2 produced a bending moment to the girder that can be calculated with a simple beam formula. The bending moment induced by the design load is displayed in Table 3.

Table 3. Girder's bending moment due to SNI 1725-2016 loading

Code	Load Type	***Moment*** **(KN.m)**
MS	Structure dead load	1348.49
MA	Additional dead load	1723.22
TD	Vehicle load	3234.12
TB	Brake load	137.91
EW	Wind load	295.83
ET	Temperature effect	95.81
EQ	Earthquake	175.24

The bending moment is the most significant external force that works in a beam structure. In a PCI girder design, the bending moment will govern the needs of the cross-section area, rebar/tendon areas, prestressed forces, and the girder's stress/strain state. The moment in Table 2 must be incorporated into a load combination formula in Table 1 to investigate the ultimate bending moment (*Mu*). By this means, several possibilities of load combination can be simulated that produce the most significant value of the ultimate moment (*Mu*). The value of Mu is then compared with the nominal capacity (Mn) of the cross-section to check the capacity of the girder.

Table 4 shows a load combination analysis result, including ultimate moment (Mu) and Mn (cross-section capacity). It is known that Combination 5 is the most significant load combination, which had an ultimate moment (Mu) of about 11,415.19 kNm. The calculated cross-section capacity produced a nominal moment (Mn) of about 13,574.19 kNm. Thus, all the loading combinations based on SNI 1725-2016 design load produced an ultimate moment that is still below the capacity of the cross-section (13,574 kNm).

Table 4. Girder Capacity Check

Load combination	**Mu (kN-m)**	**Mn (kN-m)**	**Capacity check Mu < Mn**
Comb 1	11134.29	13574.19	OK
Comb 2	11249.26	13574.19	OK
Comb 3	5239.87	13574.19	OK
Comb 4	11300.22	13574.19	OK
Comb 5	11415.19	13574.19	OK

The other important parameters regarding the SLS (service limit state) are outermost fibre stress on the cross-section and mid-span deflection. The outermost fibre stress illustrates the state of the material, and the value must not exceed the material failure stress (tension or compression). From the CSI bridge simulation, it is known that both of top (Figure 3) and bottom (Figure 4) outermost fibre in the mid-span cross-section were in the compression state. This phenomenon complies with state of the art in prestressed concrete. The presence of a prestressed tendon will bring all the cross-sections to a compression state.

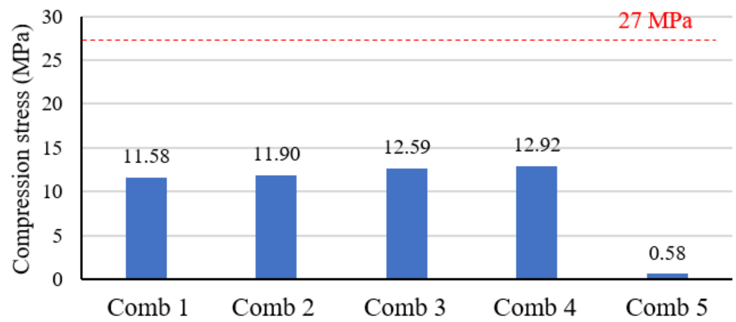

Figure 3. Outermost top fiber compression stress

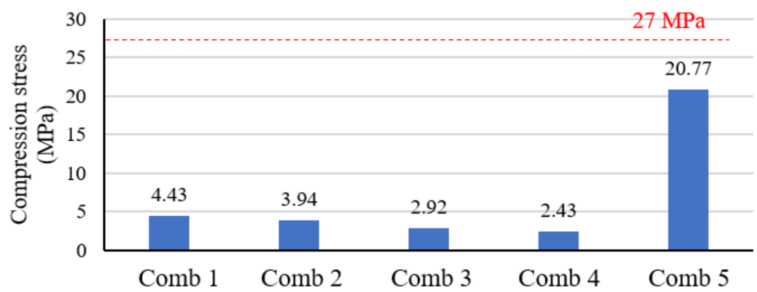

Figure 4. Outermost bottom fiber compression stress

It was obtained from the material data that the compression stress limit value for 60 MPa concrete is 27 MPa, which indicates that the concrete is starting to crack. The width of the crack must be restricted/limited to eliminate the possibilities that the water permeates to the steel bar or tendon, which initiates the corrosion. As shown in Figure 3, the top outermost fibre of the PCI girder was categorized in a compression state, and the value was still below the material crack limitation. At the same time, the bottom outermost fibre of the PCI girder also complies with the limit (27 MPa). The compression stress produced by Combination 5 is the highest stress state (20.77 MPa) but still meets the criteria.

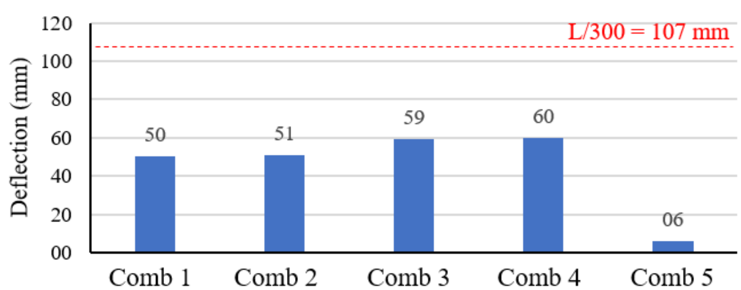

Figure 5. Mid-span deflection

Figure 5 displayed the of mid-span deflection of every load combination which ranging from 6 milimeters to 60 milimeters. The SNI 1725-2016 regulates that the maximum deflection calculated using L/300 formula. Thus, the maximum deflection for the 32.65 meters of span is 107 milimeters. From the result, it is known that the PCI girder meets the deflection criteria.

4. CONCLUSION

This paper presents a PCI girder's load and capacity analysis based on the new standard load for a bridge (SNI 1725-2016). According to the results of the research, the following concluded. Load combination consisting of dead load (MS, MA), earthquake (EQ), and prestressed force (PR) is producing the most significant loading to the bridge. The ultimate moment (*Mu*) produced from the load combination reaches 11,415 kNm, while the girder's nominal capacity (Mn) is about 13,574 kNm. Thus, the girder has enough capacity (*Mn*) to carry on the ultimate moment (Mu) produced from the design load. Several SLS parameters, including the top and bottom fibre stress and mid-span deflection, comply with the maximum limit.

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