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Analysis of Shear Forces and Flaxural Moment at Joints in PCI-Girder Precast Concrete Segmental Bridge (Case Study: Konaweha River Bridge, Southeast Sulawesi)

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Abstract:- Prestressed concrete has been widely used as a construction material, specifically for long spans bridges. Segmental precast concrete is proposed based on the following advantages: quick and easy in construction compared to cast-in-place method; better control of concrete strength; minimizes loss of prestress caused by shrinkage and creep due to properly maintained under factory controlled conditions. In this study, an analytical investigation was carried out to determine the joint shear key behavior of a PCI-girder precast concrete segmental bridges. By analyzing the value of live and dead loads applied to the bridge, the shear force and flexural moment that occurs at each joint in the segmental PCI girder will be obtained. The value of the maximum shear force that occurs at the end of the bridge is 1138 kN. the value of the maximum flexural moment that occurs in the middle of the bridge is 1111 kNm. All of these data are then used for joint girder analysis in further research, namely the analysis of joint girder modeling using the finite element method.

Keywords:- *Precast Concrete; Bridge; Simple Beam; PCI Girder; Shear Force; Flexural Moment.*

I. INTRODUCTION

Prestressed concrete has been widely used as a construction material, specifically for long spans bridges [1]. Precast is an alternative structural material with an excellent durability. Because it can be manufactured off-site at precast plant. With the efficiency of mass production processes and the high level of quality control at precast plants, lead to the high quality of precast product [2]. Segmental precast concrete is proposed based on the following advantages: quick and easy in construction compared to cast-in-place method; better control of concrete strength; minimizes loss of prestress caused by shrinkage and creep due to properly maintained under factory controlled conditions [3]. Increased erection speed, improved aesthetics, and mitigation of environmental disturbances are some of the factors that have made precast segmental construction an option in many construction projects [4].

PCI Girder splicing using longitudinal posttensioning is a competitive alternative solution for medium span bridges This technique can increase the span capacity of PCI girder and overcome the transportation and installation problems of long and heavy precast girder [5]. For the bridges with concrete shear keys are normally has one primary shear keys on the web and some secondary shear key in other parts. This joint represents the location of the discontinuity where the compressive and shear forces are transmitted. Also by applying a shear key at specific location on the web and flanges so that they can lock the external prestressing force applied to the girder. These shear key can be made as dry joint or given an epoxy coating with the main function of obtaining monolithic properties [6]. This difference between the two types of joints provides a different amount of strength.

Dry joints have a lower shear load bearing capacity between 20% to 40% less than epoxy joints [7]. There are two types of shear key joints materials which are mainly used when fabricating PCI Girder precast concrete, namely concrete match cast shear key and metal shear key. The match cast shear key is made of the concrete itself which is molded according to the specified shape which has the bearing capacity of the shear forces caused by the bridge load [8]. While the metal shear key is made of Ferro Casting Ductile (FCD) which has been widely used for construction materials based on its excellent performance. The shear key consists of two parts, a male and a female shear key, embedded on each side of the joint. The FCD metal is shown to have better characteristics than any other types of cast iron [9].

In this study, an analytical investigation was carried out to determine the joint shear key behavior of a PCI-girder precast concrete segmental bridges. By analyzing the value of live and dead loads applied to the bridge, the shear force that occurs at each joint in the segmental PCI girder will be obtained. Thus the flexural moment can also be obtained. This analysis is carried out to obtain supporting data that will be used for further research for joint analysis.

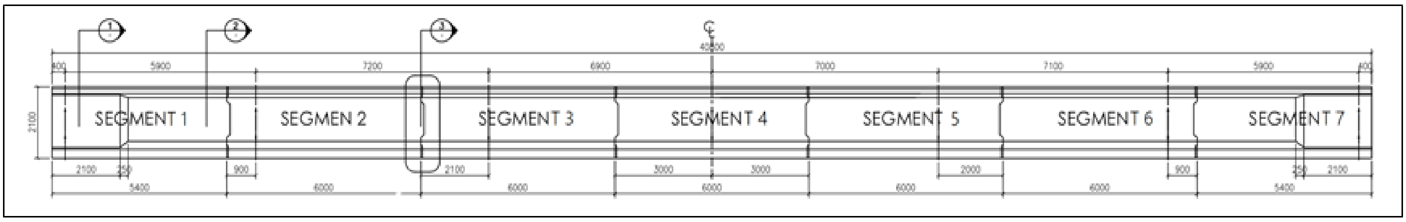

Fig. 1. Longitudinal Section of PC-I Girder

II. BRIDGE SPESIFICATION

Konaweha is the name of a river located in the province of Southeast Sulawesi on the Sulawesi island, Indonesia, about 1800 km northeast of the capital Jakarta [10]. Bridge was built to facilitate community mobilization and improve the economy of remote rural communities. The bridge is made of PC-I Girder which has a cross-sectional height of 2.1 m and a span of 40.8 m.

A. *Specification of the Bridge*

Konaweha river bridge has the following material specifications:

- Concrete strength (f'_c) : 41,5 MPa.
- Modulus of elasticity (E_c) can be obtained from:

$$E_c = 4700\sqrt{f'_c} \qquad (1)$$

- Poisson ratio (υ) : 0,15
- Shear modulus (G) can be obtained from:

$$G = \frac{E_c}{2(1+\upsilon)} \qquad (2)$$

- Initial concrete strength (f_{ci}') at transfer condition can be obtained from:

$$f'_{ci} = 0{,}8\, f'_c \qquad (3)$$

B. *Section Properties of PC-I Girder*

Konaweha river bridge has a PC-I Girder cross section with the following dimensions and is shown in Fig. 1:

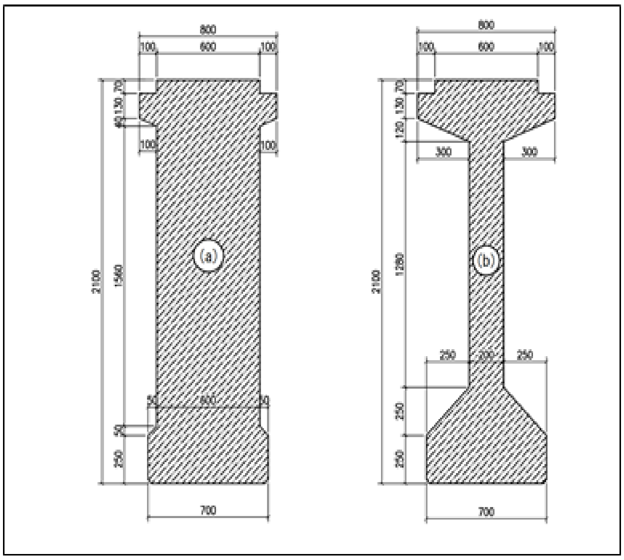

Fig. 1. Section properties: (a) at the end of the bridge, (b) in the middle of the bridge.

Fig. 1 shows that the cross-section of the girder at the end of the beam, namely near the support area, has a larger cross-sectional area. This is because the area near the support is where the greatest shear force occurs. While in the middle span area, the cross section gradually decreases. It aims to reduce the weight of the concrete itself. As we know that precast concrete bridges have a slimmer cross-section. Because to increase the strength of the beam, prestressed concrete is added..

C. *longitudinal Section of The Bridge*

Konaweha river bridge has longitudinal Section of PC-I Girder as shown in **Error! Reference source not found.**:

- Number of girders per span (n) : 5 girder
- Distance between girders (s) : 1,85 m
- Number of segment : 7 segment
- Number of diaphragm : 7 diaphragm
- PCI-Girder length : 40,8 m

III. LOAD DISTRIBUTION

Load analysis is carried out by referring to the principle of simple beam calculation. Load analysis is carried out by referring to the principle of simple beam calculation. The following equation can be used to calculate the shear force that occurs in the bridge:

$$V = \frac{1}{2} \times Q \times L \qquad (4)$$

Where the Q is the load in kN, and L is bridge span in meter (m)

- Poisson ratio (υ) : 0,15

And flexural moment can be obtained from:

$$M = \frac{1}{8} \times Q \times L^2 \qquad (5)$$

Where the flexural moment in kNm.

A. *Self-weight of the bridge*

The self-weight of the bridge is calculated based on the materials attached to the bridge. There are various other construction materials attached to the bridge such as 0.2 m thick bridge floor slab, 0.07 m thick deck slab and 0.2 m thick diaphragm. This material adds to the load and the self-weight of PC-I girder. When calculating the self-weight of the PC-I girder, it is necessary to add a value of 10% of the weight. This is to anticipate the existence of channels and utilities installed on the bridge. The self-weight components of the bridge are summarized in the following Table I. The Q_{ms} represents to the uniformly distributed load caused by the self-weight of the PC-

I girder. And the shear forces and flexural moments that occur are symbolized by V_{ms} and M_{ms}:

Table 1: Shear Forces And Flexural Moments As The Result Of The Bridge Self-Weight

Material	Uniform Distributed Load (Q_{ms})	Shear Force (V_{ms})	Flexural Moment (M_{ms})
	(kN/m)	*(kN)*	*(kNm)*
PC-I Girder	22.3	454.8	4,639.2
Deck Plate	9.3	188.7	1,924.7
Deck Slab	2.2	44.6	455.2
Diaphragm	3.2	65.4	667.0
	36.9	**753.5**	**7,686.1**

B. Additional Dead Load

Additional dead load is the weight of non-structural elements that cause additional loads on the bridge. This component is different from the self-weight materials that has been mentioned in the previous subsection. The value of additional dead load may vary over the life of the bridge. Additional dead load items can be seen in the following Table II. The Q_{ma} represents to the uniformly distributed load caused by the additional dead load of the PC-I girder. And the shear forces and flexural moments that occur are symbolized by V_{ma} and M_{ma}:

Table 2: Shear Forces and Flexural Moments as The Result of the Additional dead load

Item	Uniform Distributed Load (Q_{ma})	Shear Force (V_{ma})	Flexural Moment (M_{ma})
	(kN/m)	*(kN)*	*(kNm)*
Asphalt layer	4.1	83.0	846.9
Rainwater	0.9	18.5	188.6
	5.0	**101.5**	**1035.5**

C. Lane Load

The lane load added to the bridge analysis is the load caused by vehicles running on the bridge. The "D" lane load consists of Uniformly Distributed Loads (UDL) and Knife Edge Load (KEL). The UDL and KEL are shown in **Error! Reference source not found.**. The UDL has an intensity of q (kPa) whose magnitude depends on the length of the bridge and the distance between PC-I Girder. While KEL has an intensity of p (kPa) whose magnitude depends on the distance between the loaded girders UDL. If the span of the bridge (L) is more than 30 m, then the calculation of the value of q can be obtained from the following formula:

$$q = 8\left(0,5 + \frac{15}{L}\right) \quad (6)$$

From equation (6), the result of q is 6.94 kPa.

$$Q_{td} = q \times s \quad (7)$$

Where s is the distance between girders which is 1.85 m, so that the value of the distributed load caused by the lane load (Q_{td}) value is 12.84 kN/m. The next step is to investigate the value of the concentrated load caused by the lane load (P_{td}) on the beam. It can be obtained by the following equation:

$$P_{td} = (1 + DLA) \times p \times s \quad (8)$$

The value of Dynamic Load Allowance (DLA) for KEL on a bridge span of less than 50 m is 0.4. The KEL value (denoted by p) has a value of 44 kN/m. Thus, obtained from the equation (8), the P_{td} value becomes 113.96 kN.

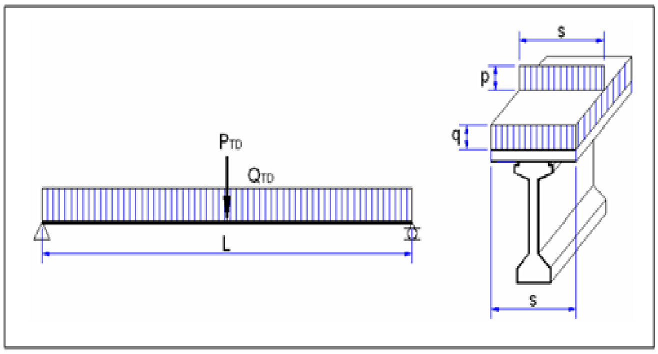

Fig. 3. an overview of the placement of UDL and KEL on the bridge

D. Brake Load

The braking effect of the vehicle produces a force that occurs in the longitudinal direction, which is called the brake load (H_{tb}). The break load is assumed to applied at a distance of 1.8 m above the deck plate which represents the location of the vehicle's center of gravity. The value of the brake load in the longitudinal direction depends on the bridge spans (L). For bridge spans less than 80 m, the H_{tb} value of 250 kN is taken. Because the number of PC-I girder at Konaweha river bridge (n) is 5 (five) beams, then the brake load that occurs on each beam (T_{tb}) is 50 kN resulting from the equation (9):

$$T_{tb} = \frac{H_{tb}}{n} \quad (9)$$

The brake load is then multiplied by the distance of the moment arm which is the distance to the center of gravity of the beam. So that the value of the resulting moment due to the brake force (M_{tb}) is 155,22 kN.

E. Wind Load

The additional uniform distributed wind load in the lateral direction on the surface of the deck plate due to the wind blowing at the vehicle (T_{ew}), is calculated by the following formula:

$$T_{ew} = 0,0012 \times C_w \times V_w^2 \quad (10)$$

The dragging coefficient (C_w) taken as 1.20 and the designed wind speed (V_w) is taken at 35 m/s. Thus from equation 10 it can be obtained that the T_{ew} value is 1.76 kN/m. The vertical height blown by the wind (h) is set at 2 m above the bridge floor which represents the maximum height of the vehicle's, and the distance between the wheels of the vehicle (x) is 1.75 m. Then, based on the following equation:

$$Q_{ew} = \frac{h \cdot T_{ew}}{2 \cdot x} \qquad (11)$$

The uniformly distributed load caused by the wind (Q_{ew}) value of 1.01 kN/m will be obtained.

F. Earthquake Load

The vertical earthquake load on the PC-I girder is calculated by the following steps. The value of the structure type factor (S) for prestressed concrete bridge with a plastic hinge area is obtained from the following equation:

$$S = 1,3(1,25 - 0,025 \cdot n_p) \qquad (12)$$

The plastic hinge area (n_p) is set at 1 (one) plastic hinge. The horizontal earthquake load coefficient can be found by the following equation:

$$K_h = C \cdot S \qquad (13)$$

with the value of the basic shear coefficient C taken of 0.125 for earthquake zone 3 on medium soil. it is necessary to find the total self-weight of the girder when determining the magnitude of the earthquake force. The total weight of one girder beam is 1710.12 kN based on the uniform distributed self-weight load calculation (Q_{ms}). The next step is to find the vertical seismic load coefficient (K_v) when the value is 50% of the horizontal seismic load coefficient (K_h) or 0.1 (the largest is taken). Then the value of the vertical earthquake load (T_{eq}) on a 40,8 m span bridge can be obtain by the following equation:

$$T_{eq} = K_v \cdot W_t \qquad (14)$$

Furthermore, it can be calculated the value of the earthquake load at each meter of the bridge span (Q_{eq}) which is 4.19 kN/m.

IV. SHEAR FORCE

After all the forces that occur on the bridge have been calculated in the previous subsection, then the shear forces acting along the span of the bridge can then be searched. The equation to obtain the shear force value at each observation point (V_x) is shown as follows:

$$V_x = Q_x \cdot \left(\frac{L}{2} - X \right) \qquad (15)$$

The uniform load for a certain type of load (Q_x) has been calculated at points A to F in the previous sub-chapter. The value of X is the distance measured from the end of the bridge.

And if the load applied is a concentrated load, as mentioned at point C in the previous sub-chapter which is called the lane load (P_{td}), then the equation to obtain the value of the shear force at each observation point (V_x) is shown as follows:

$$V_x = \frac{P_{td}}{2} \qquad (16)$$

And if the working load is a flexural moment, as mentioned at point D in the previous sub-chapter which is called the brake load (M_{tb}), the following equation is used to calculate the shear force that occurs:

$$V_x = \frac{M_{tb}}{L} \qquad (17)$$

The calculation results from equations (15) to (17) are shown in Table III caused by various types of loads that occur on the bridge. Furthermore, from Table III the shear forces that occur on the bridge are depicted in Fig. 4. The shear forces are only shown along half of the span with reference to the center line of the bridge because the shear forces are symmetrical.

V. FLEXURAL MOMENT

After all the forces that occur on the bridge have been calculated in subsection III, then the flexural moment acting along the span of the bridge can then be searched. The equation to obtain the flexural moment value at each observation point (M_x) is shown as follows:

$$M_x = \frac{Q_x \left(L \cdot X - X^2 \right)}{2} \qquad (18)$$

The uniform load for a certain type of load (Q_x) has been calculated at points A to F in subsection III. The value of X is the distance measured from the end of the bridge.

And if the load applied is a concentrated load, as mentioned at point C in subsection III which is called the lane load (P_{td}), then the equation to obtain the value of the flexural moment at each observation point (V_x) is shown as follows:

$$M_x = \frac{P_{td} X}{2} \qquad (19)$$

And if the working load is a flexural moment, as mentioned at point D in subsection III which is called the brake load (M_{tb}), then the following equation is used to calculate the flexural moment that occurs:

$$M_x = \frac{M_{tb} X}{L} \qquad (20)$$

The calculation results from equations (18) to (20) are shown in Table IV caused by various types of loads that occur on the bridge. Furthermore, from Table IV the flexural moment that occur on the bridge are depicted in Fig. 5. The shear forces are only shown along half the span with reference to the center line of the bridge because the shear forces are symmetrical.

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VI. CONCLUTION

Based on the results of the analysis, it can be conclude that the value of the Uniform Distributed Load (Q_{ms}) component of the bridge self-weight is 36,9 kN/m. The self-weight included in Q_{ms} consists of PC-I girder, deck plate, deck slab and diaphragm. So that the total weight of one PCI-girder and it's component with span length 40,8 m is 1710.12 kN. The value of the Uniform Distributed Load of additional dead load (Q_{ma}) is 5 kN/m. The additional dead load included in Q_{ma} consists of asphalt layer and rainwater. The lane load (P_{td}) added to the bridge analysis is the load caused by vehicles running on the bridge. From the analysis result, the lane load (P_{td}) value becomes 113.96 kN. The braking effect of the vehicle produces a brake load that occurs on each beam (T_{tb}). Than the brake load is then multiplies by the distance of the moment arm which is the distance to the center of gravity of the beam. So that the value of the resulting moment due to the brake force (M_{tb}) is 155,22 kN. The additional uniform distributed wind load (Q_{ew}) in the lateral direction on the surface of the deck plate due to the wind blowing at the vehicle is 1.01 kN/m. The value of the earthquake load at each meter of the bridge span (Q_{eq}) is 4.19 kN/m. From Table III it can be seen that the value of the maximum shear force that occurs at the end of the bridge is 1138 kN from combination 3. From Table IV it can be seen that the value of the maximum flexural moment that occurs in the middle of the bridge is 1111 kN.m from combination 3. All of these data are then used for joint girder analysis in further research, namely the analysis of joint girder modeling using the finite element method.

Table 3 Table Of Shear Forces On Half Bridge

Distance (X)	**Shear Force as the Result of:**						**Comb. 1**	**Comb. 2**	**Comb. 3**	**Comb. 4**
	Self-weight	**Additional Dead load**	**Lane Load**	**Break Load**	**Wind Load**	**Earthquake Load**	***MS+MA +TD+TB***	***MS+MA +TD+EW***	***MS+MA+TD +TB+EW***	***MS+MA +EW+EQ***
	MS	***MA***	***TD***	***TB***	***EW***	***EQ***				
(m)	*(kN)*	*(kN)*	*(kN)*	*(kN)*	*(kN)*	*(kN)*	*(kN)*	*(kN)*	*(kN)*	*(kN)*
0	727	93	293	4	21	82	1117	1134	1138	923
1	691	89	281	4	20	78	1065	1081	1085	878
2	656	84	269	4	19	74	1013	1028	1032	832
3	620	80	258	4	18	70	961	975	979	787
4	584	75	246	4	17	66	909	922	926	742
5	549	70	234	4	16	62	857	869	873	697
6	513	66	222	4	15	58	805	816	820	651
7	477	61	210	4	14	54	753	763	767	606
8	442	57	199	4	12	50	701	710	714	561
9	406	52	187	4	11	46	649	657	661	516
10	371	48	175	4	10	42	597	604	608	470
11	335	43	163	4	9	38	545	551	555	425
12	299	38	151	4	8	34	493	498	501	380
13	264	34	140	4	7	30	441	445	448	335
14	228	29	128	4	6	26	389	392	395	290
15	192	25	116	4	5	22	337	339	342	244
16	157	20	104	4	4	18	285	286	289	199
17	121	16	92	4	3	14	233	233	236	154
18	86	11	81	4	2	10	181	180	183	109
19	50	6	69	4	1	6	129	127	130	63
20.4	0	0	52	4	0	0	56	52	56	0

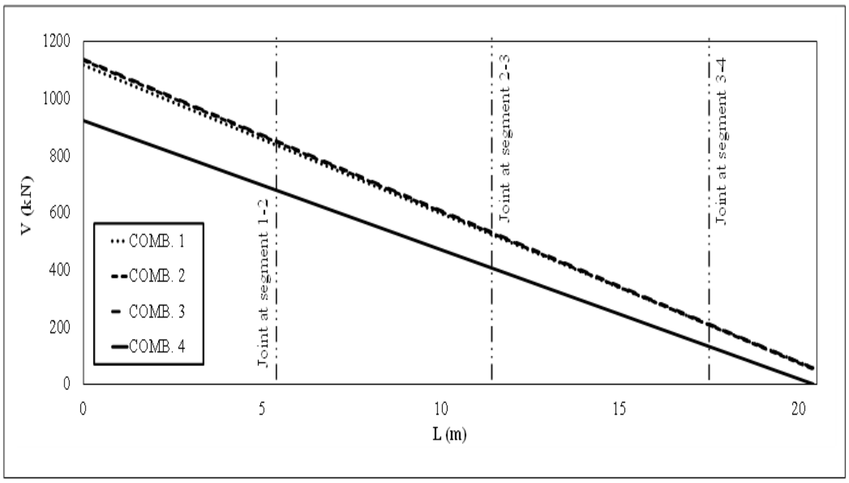

Fig. 4 Shear Force Diagram of half of the bridge

Table 4 Table Of Flexural Moment On Half Bridge

Distance (X)	**Flexural Moment as the Result of:**						**Comb. 1**	**Comb. 2**	**Comb. 3**	**Comb. 4**
	Self-weight	**Additional Dead load**	**Lane Load**	**Break Load**	**Wind Load**	**Earthquake Load**	***MS+MA +TD+TB***	***MS+MA +TD+EW***	***MS+MA+TD +TB+EW***	***MS+MA +EW+EQ***
	MS	***MA***	***TD***	***TB***	***EW***	***EQ***				
(m)	*(kNm)*	*(kNm)*	*(kNm)*	*(kNm)*	*(kNm)*	*(kNm)*	*(kNm)*	*(kNm)*	*(kNm)*	*(kNm)*
0	0	0	0	0	0	0	0	0	0	0
1	709	91	287	4	20	80	1091	1107	1111	900
2	1383	177	563	8	39	156	2130	2162	2169	1755
3	2020	259	826	11	57	228	3117	3163	3174	2565
4	2623	337	1078	15	74	296	4052	4111	4127	3329
5	3189	409	1318	19	90	360	4935	5007	5026	4049
6	3720	477	1546	23	105	420	5767	5849	5872	4723
7	4216	541	1762	27	119	476	6546	6638	6665	5351
8	4675	600	1967	30	132	528	7273	7374	7405	5935
9	5099	654	2160	34	144	575	7948	8058	8092	6473
10	5488	704	2341	38	155	619	8571	8688	8726	6966
11	5840	750	2510	42	165	659	9142	9265	9307	7414
12	6158	790	2667	46	174	695	9661	9789	9835	7817
13	6439	826	2813	49	182	727	10128	10261	10310	8174
14	6685	858	2947	53	189	754	10543	10679	10732	8486
15	6895	885	3069	57	195	778	10906	11044	11101	8753
16	7070	907	3179	61	200	798	11217	11356	11417	8975
17	7209	925	3277	65	204	813	11476	11615	11680	9151
18	7312	938	3364	68	207	825	11683	11821	11890	9282
19	7380	947	3439	72	209	833	11838	11974	12047	9368
20.4	7415	952	3523	78	210	837	11967	12100	12177	9413

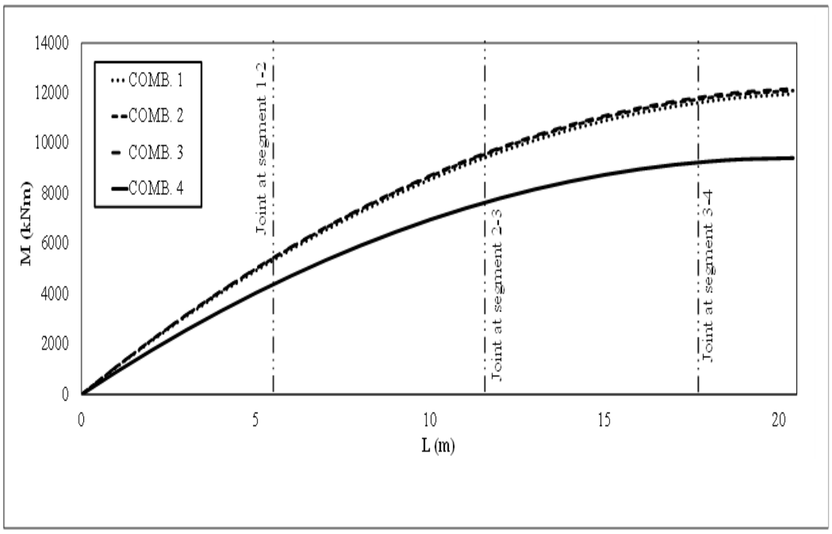

Fig. 5 Flexural Moment Diagram of half of the bridge

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